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Effect of Climate Change Adaptation Strategies on Smallholder Farmer's Maize Production in Tanzania

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Abstract

This study investigates the effect of climate change adaptation strategies on smallholder farmers' maize production in Tanzania, using data from the 2019/20 National Sample Census of Agriculture (NSCA) by the National Bureau of Statistics. A multiple linear regression model was employed to assess how demographic, socio-economic, institutional, and adaptation-related factors influence maize output. The findings revealed that land size (β = 0.009, p = 0.069) and membership in farmers' organizations (β = 0.747, p = 0.086) were positively and significantly associated with maize production, highlighting the importance of land access and collective action in enhancing productivity. Among adaptation strategies, contour farming (β = 0.370, p = 0.008), planting of legumes (β = 0.427, p = 0.002), intensive use of organic fertilizer (β = 0.252, p = 0.078), and fallowing (β = 0.484, p = 0.001) all had statistically significant and positive effects on maize yield. These results indicate that sustainable land management and soil fertility improvement practices substantially enhance maize productivity under climate stress. Specifically, contour farming and fallowing emerged as the most impactful adaptation measures, reinforcing the value of traditional and indigenous practices in modern resilience frameworks. The study concludes that integrating both ecological and institutional dimensions such as secure land tenure, farmer organization strengthening, and promotion of organic soil management is vital for sustainable adaptation. Policy implications emphasize the alignment of these findings with Tanzania's National Climate-Smart Agriculture Programme (NCSAP) and Agriculture Sector Development Programme (ASDP II) to promote adaptive, inclusive, and productivity-enhancing farming systems.

Keywords: *Climate Change Adaptation strategies, Smallholder farmers, Maize Production*

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I. Introduction

Climate change has become a major global threat to maize production, with rising temperatures, erratic rainfall, droughts, and extreme weather reducing agricultural productivity across both developed and developing countries. In developed regions such as the United States, Europe, Canada, and Australia, climate change has caused declining or unstable maize yields despite the widespread adoption of advanced adaptation measures, including precision agriculture, drought-tolerant crop varieties, soil moisture conservation, improved irrigation, artificial intelligence, and climate modeling (FAO, 2023; USDA, 2024; Eurostat, 2023; EEA, 2024; Wu et al., 2025). Across Africa, maize yields have declined by 10–25% because of increasing droughts, floods, rising temperatures, and pest outbreaks, although practices such as conservation agriculture, drought-tolerant varieties, crop diversification, and small-scale irrigation have improved resilience where implemented (FAO, 2024; Zenda, 2024; Dlamini et al., 2026). However, adoption of these climate-smart practices remains constrained by limited financial resources, inadequate institutional support, and poor access to extension services.

In Tanzania, climate change has significantly reduced maize productivity, with yield losses of 15–30% reported in major maize-producing regions due to increasing temperatures and erratic rainfall (Mohamed, 2024; Nassary & Magubika, 2025; Volk et al., 2021). Although initiatives such as the National Climate-Smart Agriculture Programme (2021–2031), irrigation development, drought-tolerant maize varieties, climate field schools, and intercropping have improved resilience in some areas, adaptation remains limited, with only about 43% of smallholder farmers adopting climate-smart practices by 2025 because of inadequate financing, limited access to agricultural information, and gender-related barriers (Mdemu et al., 2025; Mosha & Ngulube, 2025; Mbunda & Ndunguru, 2025; Laurent & Mushi, 2024). Without broader implementation of effective adaptation strategies, climate change is expected to further reduce maize production, worsen food insecurity, and threaten the livelihoods of smallholder farmers, underscoring the need to assess the effectiveness of climate change adaptation strategies in Tanzania.

II. Theoretical Review

The Production Theory

Production Theory provides a theoretical framework for explaining how agricultural inputs are transformed into outputs under given technological and environmental conditions. Developed by Marshall (1890) and further advanced by Douglas and Cobb (1928) through the Cobb-Douglas production function, the theory explains the relationship between factors of production such as land, labor, capital, and total output. It assumes that farmers make rational decisions to maximize productivity by efficiently combining available resources. In agricultural production, the theory helps explain how smallholder farmers combine land, labor, seeds, fertilizers, and other inputs to achieve higher maize yields. Its application is particularly relevant in climate change studies because adaptation strategies influence the efficiency and productivity of traditional agricultural inputs.

The traditional Cobb-Douglas production function is expressed as:

$$Y = A.L^{\alpha}.K^{\beta}$$

Where:
Y= maize output,

A = total factor productivity (representing technology, climate conditions, and farming efficiency),
L = labor input,
K = capital inputs such as seeds, fertilizers, and agricultural equipment,
α and β = output elasticities of labor and capital.

In this study, the production function is extended to incorporate climate change adaptation strategies as additional inputs influencing maize productivity. The extended model is specified as:

$$Y = A.L^{\alpha}.K^{\beta}.Y_{1i}^{\gamma}$$

Where (Y_{1i}) represents climate adaptation strategies adopted by smallholder farmers, including contour farming, covering soil with grass or leaves (mulching), fallowing, intensive use of organic fertilizer, and planting legumes. The parameter γ measures the responsiveness of maize output to each adaptation strategy. A positive value of γ implies that adoption of these practices increases maize productivity by improving soil fertility, conserving moisture, reducing erosion, and enhancing resilience to climate variability.

Although Production Theory provides a useful analytical foundation, it has limitations because its assumptions of perfect information, rational decision-making, and fixed technology may not fully represent the conditions of smallholder farmers. In Tanzania, farmers often face constraints such as limited access to credit, inadequate climate information, input market challenges, land degradation, and gender-related inequalities, which affect their ability to optimize production decisions. Despite these limitations, the theory remains valuable for understanding how combining conventional agricultural inputs with climate adaptation practices influences maize productivity. Practices such as contour farming and mulching improve soil moisture retention, while organic fertilizer use, legume integration, and fallowing enhance soil fertility and overall productivity, demonstrating how adaptation strategies contribute to increased maize output under changing climatic conditions.

III. Empirical Literature Review

Existing studies show that climate change significantly threatens agricultural productivity, especially for staple crops such as maize, wheat, rice, and soybeans. Research indicates that rising temperatures, drought, irregular rainfall, and extreme weather events reduce crop yields, while adaptation strategies such as improved irrigation, climate-resilient varieties, optimized input use, crop rotation, and sustainable soil management can enhance resilience (Eyshi-Rezaei et al., 2023; Habib-ur-Rahman et al., 2022; Rosa, 2022; Zhu et al., 2024; Yu et al., 2022). However, studies by Farooq et al. (2023) and Neupane et al. (2022) highlight that climate impacts are expected to worsen in tropical and subtropical regions, with significant risks to cereal production if effective adaptation measures are not implemented. Despite these contributions, many existing studies focus on global or large-scale agricultural systems and provide limited understanding of how smallholder farmers' socioeconomic, institutional, and local environmental conditions influence adaptation decisions. This gap emphasizes the need for context-specific research, particularly in Tanzania, to examine the effectiveness of climate change adaptation strategies among smallholder maize farmers.

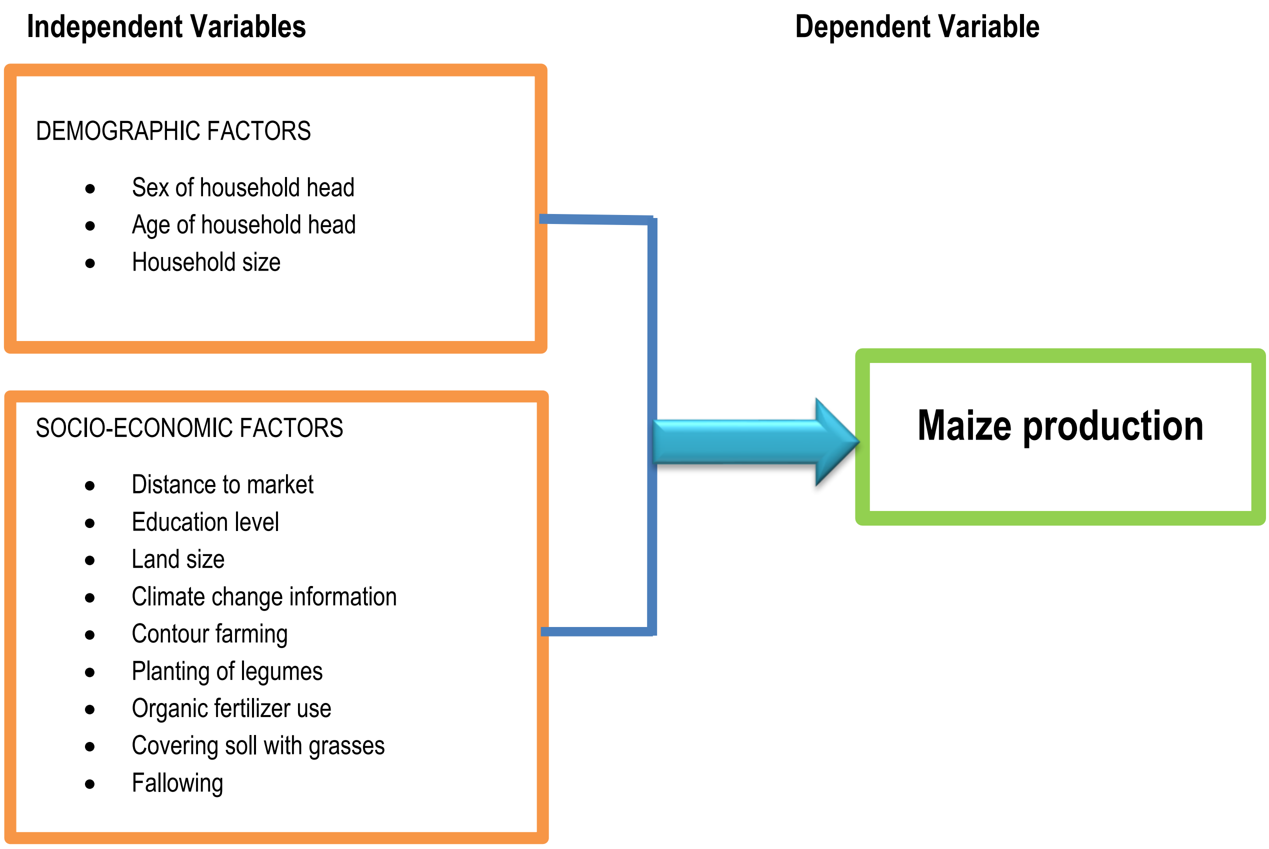

Figure 1: Conceptual Framework

The conceptual framework in Figure 1 illustrates how demographic and socio-economic factors collectively influence maize production among smallholder farmers in Tanzania. It shows that demographic factors such as sex, age, household size, and marital status affect farmers' decision-making capacity, labor availability, and adaptation behavior. Meanwhile, socio-economic factors including distance to water source, years of schooling, land size, location, access to credit, access to clean water, access to extension services, access to markets, and exposure to climate change information directly determine the farmers' access to resources, knowledge, and technology needed for effective production. Furthermore, specific adaptation practices such as contour farming, covering with grass, fallowing, intense use of organic fertilizer, and planting legumes enhance soil fertility and moisture retention, thereby improving yields under changing climatic conditions. Together, these variables interact to determine the overall efficiency, resilience, and productivity of maize farming, highlighting how social, economic, and adaptive factors shape agricultural outcome.

IV. Materials and Methods

Research Design

The current study adopted a statistical research design, utilizing secondary data from the 2019/20 National Sample Census of Agriculture (NSCA) conducted by the National Bureau of Statistics (NBS) in collaboration with the Office of the Chief Government Statistician (OCGS) in Zanzibar. This design enabled the use of a large, nationally representative dataset that includes detailed information on demographic, socio-economic, and farm-level characteristics of agricultural households across Tanzania. The study specifically focused on smallholder maize farmers, analyzing how various demographic, socio-economic, and climate adaptation factors influence maize production. By applying statistical techniques to quantify relationships between variables such as land size, education level, access to extension services, and adoption of climate-smart practices the research design provided a systematic and empirical framework for examining production efficiency and adaptation outcomes. This quantitative approach ensured objectivity, reproducibility, and precision in identifying key determinants of maize productivity under changing climatic and socio-economic conditions.

Study Area

Tanzania was selected as the study area for this research due to its strong dependence on agriculture, significant vulnerability to climate change, and the critical role maize plays in ensuring national food security and rural livelihoods. Agriculture contributes approximately 26% to Tanzania's GDP and employs about 65% of the labor force, with smallholder farmers constituting over 80% of total agricultural producers (NBS, 2021; FAO, 2024). Maize is the country's most important staple crop, cultivated by over 70% of rural households and accounting for nearly 45% of total cereal production (URT, 2024). Despite its importance, maize production remains heavily dependent on rainfall, making it highly susceptible to the impacts of climate variability especially in semi-arid regions such as Dodoma, Singida, Manyara, and Iringa. Between 2019 and 2024, the country experienced recurrent droughts and erratic rainfall patterns that led to maize yield declines of 10–25%, particularly in the central and northern zones (Nassary & Magubika, 2025).

Tanzania also provides an ideal case for examining climate change adaptation strategies, as the government has actively promoted initiatives such as the Agriculture Sector Development Programme Phase II (ASDP II) and the National Climate-Smart Agriculture Programme (NCSAP, 2021–2031), which encourage practices like contour farming, use of organic fertilizers, and legume intercropping. However, adoption rates remain uneven across regions due to differences in access to land, credit, extension services, and market linkages. Furthermore, the country's diverse agro-ecological zones, ranging from humid coastal areas to semi-arid plateaus, provide a unique opportunity to analyze how demographic, socio-economic, and environmental factors interact to influence maize production outcomes. Statistically, Tanzania's average maize yield remains around 1.8–2.1 tons per hectare, well below the potential yield of 4.5 tons/ha, demonstrating a substantial yield gap of over 50% (FAO, 2024). Addressing this gap through effective adaptation strategies is critical for ensuring food security and poverty reduction. The spatial focus on Tanzania therefore enables a comprehensive understanding of how climate change adaptation strategies affect maize productivity within a context characterized by diverse climatic zones, socio-economic conditions, and farming systems. The study's findings are expected to contribute to policy formulation and inform regional development programs aimed at improving agricultural resilience and sustainability.

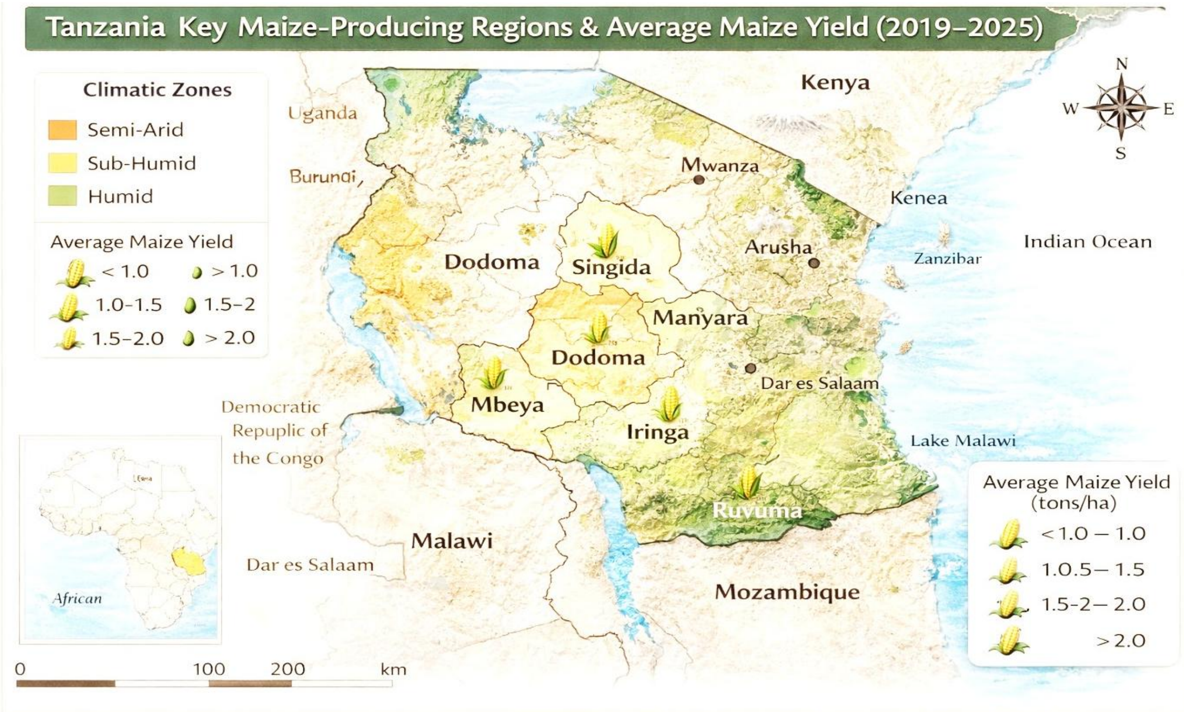

Figure 2: Study Area

Population

The 2019/20 National Sample Census of Agriculture (NSCA) covered all agricultural households and large-scale farms engaged in crop and livestock production across Tanzania, including smallholder farmers producing annual and permanent crops, livestock, fish, and beekeeping. For this study, the focus is on smallholder maize farmers because maize is Tanzania's principal staple crop and a major source of rural livelihoods and household income. The census included a total of 33,808 smallholder agricultural households, comprising 32,008 from Mainland Tanzania and 1,800 from Zanzibar, providing a nationally representative population for analyzing maize production and climate change adaptation.

Data Source

This study uses secondary data from the 2019/20 National Sample Census of Agriculture (NSCA), conducted by the National Bureau of Statistics (NBS) in collaboration with the Office of the Chief Government Statistician (OCGS) in Zanzibar under the Government of Tanzania's Poverty Monitoring Master Plan. The census collected nationally representative data using the Smallholder Farmers, Large-Scale Farms, and Community-Level Questionnaires through Computer-Assisted Personal Interviewing (CAPI), providing comprehensive information on agricultural activities, household demographics, resource access, and the socio-economic characteristics of farming households across Mainland Tanzania and Zanzibar.

Sampling Technique

The census adopted a two-stage stratified sampling design. In the first stage, Enumeration Areas (EAs) from the 2012 Population and Housing Census were used as Primary Sampling Units (PSUs). These EAs were explicitly sorted by region and district, and selection was made using the Probability Proportional to Size (PPS) method to ensure representativeness. In the second stage, a selection of agricultural households within each sampled EA was conducted as secondary sampling units. The design ensured that both rural and urban areas were adequately represented, with a heavier focus on rural EAs due to the predominance of agricultural households. This technique was chosen to minimize sampling error and allow reliable disaggregation of results at the regional and district levels.

Sample size

Although the 2019/20 National Sample Census of Agriculture (NSCA) covered all agricultural households, this study focused specifically on smallholder maize-producing households due to maize's importance as Tanzania's leading staple crop. From the census dataset, 9,826 maize-producing households were identified, while other crop producers were excluded due to their smaller and uneven distribution across regions. The final analytical sample consisted of 2,993 observations, which was considered adequate for the econometric model containing 23 independent variables. Based on established sample size guidelines, including Hair et al. (2019), who recommend 10–20 observations per predictor, and Green's (1991) rule of N > 50 + 8m, the required minimum sample size was far below the available observations. Therefore, the sample size provides sufficient statistical power, reliable parameter estimates, and strong generalizability of the findings to Tanzania's smallholder maize farming population.

Unit of analysis

The unit of analysis for the 2019/20 NSCA included individuals, households, large-scale farms, and communities. For smallholder agriculture, the household served as the main analytical unit since data collection focused on household-level agricultural production, land ownership, resource access, and socio-economic conditions. For large-scale farms, each farm entity whether privately or corporately managed was treated as a separate analytical unit. At the community level, the village served as the unit of analysis for assessing access to communal resources, infrastructure, and environmental conditions. This multi-level analysis framework provided a comprehensive understanding of Tanzania's agricultural sector from both household and community perspectives.

Data collection technique

Data collection for the 2019/20 NSCA was conducted between August and October 2020 using the Computer-Assisted Personal Interviewing (CAPI) method. Enumerators used electronic tablets preloaded with structured questionnaires to collect data in real time, which improved accuracy and efficiency in the field. Three types of questionnaires were used: the Smallholder Farmers Questionnaire, the Large-Scale Farms Questionnaire, and the Community-Level Questionnaire. Data collection was supervised through a hierarchical system consisting of Mobile Response Teams, Regional Supervisors, and District Supervisors, ensuring adherence to procedures and quality control. This structured approach allowed real-time monitoring, timely corrections, and data validation during the fieldwork phase.

Measurement of Variables

	Variables	**Description**	**Expected signs**
	Dependent variable		
q811c9b	***Maize Production***	Quantity of output harvested	
	Independent variable		
q3_1c3	Sex of household head	A dummy variable is assigned a value of 1 if a household head is male and 0 if is female	+/-
q3_1c4	Age of household age	Number of years of household head	+/-
q7_1c4	Distance to market	Distance to market in Km	+/-

q3_1c9	Household educational level	Number of schooling years of household head	-
q5_1_13	Land Size	Continuous size of the land	+
q3_1c16	Cooperative membership	1 if households in cooperative 0 if households not in cooperative	+/-
q330c0	Source Market information	1 for TV 2 Radio 3 for Newspaper 4 for Mobile Phones 5 for Local Authorities 6 for Farmers Organization 7 for Internet 8 for Fellow farmers 9 others	+/-
q14_1	Access to extension services	Dummy (1= accessed, 0 = otherwise)	+/-
q330c2	Access to market	Dummy (1= accessed, 0 = otherwise)	+/-
q3_1c13	Land ownership	1 household own a piece of land 0 not own a piece of land	
q124c0	Type of farm input used	1 Chemical Fertilizer 2 Farm Yard Manure 3 Compost Manure 4 Insecticide/fungicide 5 Herbicide 6 Improved Seeds	
q6_2c0	Adaptation strategies		
	Contour Farming	Dummy (1= Use, 0 = otherwise)	+/-
	Covering with grass	Dummy (1= Use, 0 = otherwise)	+/-
	Fallowing	Dummy (1= Use, 0 = otherwise)	+/-
	Intense use of organic fertilizer	Dummy (1= Use, 0 = otherwise)	+/-
	Planting legumes	Dummy (1= Use, 0 = otherwise)	+/-

Data analysis

This study employed a Multiple Regression Analysis (MRA) framework to examine how demographic, socio-economic, and climate change adaptation factors influence maize production among smallholder farmers in Tanzania. The use of Multiple Regression Analysis was justified by the nature of the dependent variable, which is continuous measured in terms of total maize output (e.g., kilograms or tons per household). Unlike binary or categorical outcomes analyzed using logit or probit models, which are suited for “yes/no” or “0/1” type dependent variables, MRA is appropriate for modeling continuous quantitative data, where the objective is to estimate how changes in multiple independent variables simultaneously affect the level of production. Therefore, MRA enables the study to not only identify which factors influence maize output but also quantify the magnitude and direction of their effects, holding other factors constant.

Moreover, the nature of the research problem understanding how much demographic, socio-economic, and adaptation factors contribute to maize productivity requires a linear estimation approach rather than a probabilistic one. Logit and probit models, by contrast, are more suitable for studies that assess adoption decisions (e.g., whether a farmer adopts irrigation or not) rather than continuous production outcomes. The MRA approach, estimated using the Ordinary Least Squares (OLS) method, also offers simplicity in interpretation and allows for testing of marginal effects and significance levels of each predictor, which is critical for informing agricultural policy and extension planning.

The Multiple Regression Analysis (MRA) used in this study is based on several key assumptions that ensure the validity and reliability of the estimated coefficients. First, it assumes a linear relationship between the dependent variable (maize production) and all independent variables, meaning that changes in predictors have a proportional effect on output. Second, the independent variables are measured without error and are not perfectly correlated, implying the absence of multicollinearity among predictors. Third, the error term (εi) is assumed to have a mean of zero and constant variance (homoskedasticity) across all observations, ensuring that the variability of errors is consistent throughout the dataset. Fourth, the error terms are independent of each other, implying that observations are not autocorrelated, which is crucial for cross-sectional agricultural data. Lastly, the residuals are assumed to be normally distributed, allowing valid hypothesis testing and significance inference. Meeting these assumptions ensures that the Ordinary Least Squares (OLS) estimator used in the MRA is unbiased, consistent, and efficient, thereby producing statistically sound and interpretable results for policy and decision-making in the context of maize production.

Model Specification

The general form of the multiple regression model is:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \beta_5 X_{5i} + \cdots \dots \dots \dots . + \beta_k X_{ki} + \varepsilon_i$$

Where:

Y_i =Maize production (output per household in kilograms or tons)

$\beta_0 = \text{Intercept term}$

$\beta_1, \beta_2, \dots \dots . \beta_k$ = Coefficients representing the effect of each independent variable

$X_{1i}, X_{2i}, X_{3i}, \dots \dots \beta_k X_{ki}$ = Independent variables

ε_i = Random error term

Empirical Model for the Study

The empirical specification for the current study is:

$$MP_i = \beta_0 + \beta_1 SEX + \beta_2 AGE + \beta_3 HHSIZE + \beta_4 MSTAT + \beta_5 ADAPTASTRATEGIES + U_i$$

V. Results

Descriptive Statistics

This section presents a comprehensive analysis of socio-demographic characteristics, institutional access, input usage, adaptation strategies, and production outcomes. This section presents descriptive statistics that shed light on the profiles of the respondents and the contextual variables that influence their agricultural decisions.

The descriptive results show that among the 2,993 respondents, 54.96% were male and 45.04% were female, indicating substantial participation of both genders in smallholder maize farming and highlighting the need for gender-sensitive climate adaptation interventions. Only 41.60% of respondents owned agricultural land, while 58.40% did not, suggesting widespread land insecurity that may constrain long-term investments in climate-smart agriculture. Access to market information (14.20%) and agricultural extension services (5.68%) was very limited, indicating major barriers to informed decision-making and the adoption of improved adaptation practices. Nearly all respondents (98.96%) belonged to cooperatives, reflecting strong social capital that can be leveraged to disseminate climate adaptation knowledge, improve access to inputs and credit, and support community-based adaptation. Farmers obtained market information through a diverse mix of traditional, digital, and interpersonal channels, with no single source dominating, demonstrating the growing integration of multiple communication systems.

Table 1: Descriptive statistics

Variables	Categories	Frequency (Percentage)
Gender	Male	1645 (54.96%)
	Female	1348 (45.04%)
Land Ownership	Yes	1245 (41.60%)
	No	1748 (58.40%)
Access to Market Information	Yes	425 (14.20%)
	No	2568 (85.80%)
Received Extension Advice	Yes	170 (5.68%)
	No	2823 (94.32%)
Membership in Cooperative/Org.	Yes	2962 (98.96%)
	No	31 (1.04%)
Market information sources	Television	1098(11.11%)
	Radio	1098(11.11%)
	News papers	1098(11.11%)
	Mobile Phones	1097(11.10%)
	Local Authorities	1098(11.11%)
	Farmers Organization	1098(11.11%)
	Internet	1098(11.11%)
	Fellow Farmers	1098(11.11%)
	Other (Specify)	1098(11.11%)
Climate change strategies	Contour farming	494 (16.51%)
	Planting of legumes	503 (16.81%)
	Organic fertilizer use	492 (16.44%)
	Covering soil with grasses	523 (17.47%)
	Fallowing	513 (17.14%)
	Other	468 (15.64%)

Variable	Obs	Mean	Std. Dev.	Min	Max
Maize Production	2,993	328.9245	1766.811	1	72,225
Age	2,993	37.76478	15.46581	18	96
Distance to market	2,993	20.57534	32.57198	1	99
Land Size	2,993	5.147554	9.180059	0	148

Source: Computation from 2019/20 National Sample Census of Agriculture

The most commonly adopted adaptation strategies were covering soil with grasses or leaves (17.47%), fallowing (17.14%), planting legumes (16.81%), contour farming (16.51%), organic fertilizer use

(16.44%), and other practices (15.64%), indicating that farmers rely on complementary approaches to address climate variability rather than a single dominant strategy. Average maize production was 328.92 kg per household (SD = 1,766.81; range: 1–72,225 kg), revealing substantial disparities in productivity likely driven by differences in land size, input use, adaptation practices, and market access. Farmers had a mean age of 37.76 years (SD = 15.47; range: 18–96 years), suggesting participation by both economically active adults and older farmers, while the average distance to the nearest market was 20.58 km (SD = 32.57; range: 1–99 km), highlighting considerable inequalities in market accessibility that may hinder adaptation investments. Finally, the average landholding was 5.15 acres (SD = 9.18; range: 0–148 acres), reflecting significant disparities in land ownership, with many farmers operating on small or no land and only a few possessing large holdings, factors that directly influence their capacity to adopt and sustain climate change adaptation strategies.

Table 2: Effect of Climate Change Adaptation Strategies on Smallholder Farmer's Maize Production

Variable	Coefficient	Std. Error	P-value
Gender			
Male	0.044	0.086	0.613
Demographics			
Age	-0.003	0.003	0.363
Distance to Market	-0.002	0.001	0.164
Education Level			
Secondary Education	0.253	0.182	0.165
University & Other Tertiary	0.162	0.205	0.429
Household & Institutional Factors			
Land Size (Acres)	0.009*	0.005	0.069
Farmers' Org. Membership (Yes)	0.747*	0.434	0.086
Cooperative Membership	-0.002	0.097	0.982
Extension Advice (Yes)	0.248	0.177	0.161
Market Access (Yes)	0.044	0.134	0.744
Market Information Sources			
Radio	-0.033	0.171	0.848
Newspapers	-0.208	0.171	0.225
Mobile Phones	-0.078	0.169	0.645
Local Authorities	-0.079	0.173	0.647
Farmers' Organization (Info Source)	-0.082	0.173	0.634
Internet	0.085	0.169	0.617
Fellow Farmers	0.009	0.184	0.961
Others	0.057	0.177	0.749
Climate Adaptation Strategies			
Contour Farming	0.370***	0.14	0.008
Planting of Legumes	0.427***	0.139	0.002
Intense Use Organic Fertilizer Use	0.252*	0.143	0.078
Covering Soil with Leaves/Grasses	0.221	0.144	0.124
Fallowing	0.484***	0.141	0.001
Constant	1.337**	0.606	0.028

**** p<.01, ** p<.05, * p<.1*

Source: Computation from 2019/20 National Sample Census of Agriculture

Post-diagnosis tests

The Variance Inflation Factor (VIF) results indicate that multicollinearity is not a problem in the regression model, as individual VIF values range from 1.01 to 3.48 with a mean VIF of 1.745, well below the commonly accepted thresholds of 10 (Gujarati, 2004; Hair et al., 2019) and the more conservative threshold of 5 (O'Brien, 2007). The corresponding tolerance values (0.288–0.988), all exceeding the acceptable minimum of 0.2, further confirm that the explanatory variables are not highly correlated and each contributes unique information to the model. Therefore, the regression coefficients are considered statistically reliable, allowing the relationships between climate adaptation strategies and maize productivity to be interpreted with confidence, without concerns of multicollinearity bias.

Table 3: Variance Inflation Factor

	VIF	1/VIF
Sex of household head	1.232	.812
Age of household head	1.386	.721
Distance to market	1.012	.988
Household educational level (Secondary)	3.475	.288
Household educational level (University)	3.472	.288
Land Size	1.01	.99
Cooperative membership	1.013	.987
Market information: Radio	1.776	.563
Market information: Newspapers	1.749	.572
Market information: Mobile Phones	1.835	.545
Market information: Local Authorities	1.794	.557
Market information: Farmers Organization	1.774	.564
Market information: Internet	1.857	.538
Market information: Fellow Farmers	2.21	.452
Market information: Other sources	1.777	.563
Access to extension services	1.011	.989
Access to market information	1.437	.696
Land ownership	1.622	.617
Adaptation strategy: Contour farming	1.727	.579
Adaptation strategy: Planting of legumes	1.733	.577
Adaptation strategy: Organic fertilizer use	1.724	.58
Adaptation strategy: Covering soil with grass	1.753	.57
Adaptation strategy: Fallowing	1.745	.573
Mean VIF	**1.745**	**.**

Source: Computation from 2019/20 National Sample Census of Agriculture

The Breusch–Pagan/Cook–Weisberg test in Table 4 produced a chi-square value of 17.10 with a p-value of 0.0000, which is highly significant at the 1% level. This leads to the rejection of the null hypothesis (H_0) of constant variance, confirming the presence of heteroscedasticity in the model. To address this problem and ensure reliable statistical inference, the study employed heteroscedasticity-robust standard errors (Huber–White estimators), which correct for non-constant variance and yield consistent and efficient parameter estimates. The use of robust regression allowed for valid statistical inference even in the presence of non-constant error variance, providing consistent and efficient estimates of the model parameters.

Interpretation of the Regression Results

The regression results indicate that several climate adaptation strategies and farm characteristics have a positive and statistically significant influence on maize production. Land size positively affects maize output ($\beta = 0.009$, $p < 0.1$), suggesting that farmers with larger plots are better able to allocate resources efficiently and adopt climate-smart agricultural practices. Membership in farmers' organizations also significantly increases maize production ($\beta = 0.747$, $p < 0.1$), reflecting the benefits of collective action through improved access to extension services, training, shared knowledge, and production inputs. Similarly, contour farming has a strong positive effect on maize productivity (β = 0.370, p = 0.008), demonstrating that soil and water conservation practices remain effective adaptation measures under changing climatic conditions.

Heteroscedasticity

Table 4: Heteroscedasticity

Test	Assumption	Variable Tested	Chi^2 (1)	Prob > Chi^2	Decision (5% Level)	Conclusion
Breusch–Pagan / Cook–Weisberg Test	Normal error terms	Fitted values of ln (Maize Quantity)	17.10	0.0000	Reject H_0	Heteroscedasticity detected

Among the adaptation strategies, planting legumes (β = 0.427) and the intense use of organic fertilizer (β = 0.252, p < 0.1) significantly improve maize production by enhancing soil fertility, moisture retention, and nutrient availability while reducing dependence on synthetic inputs. Fallowing emerged as the most effective adaptation practice (β = 0.488, p < 0.01), indicating that temporarily resting farmland promotes soil regeneration, interrupts pest and disease cycles, and substantially increases subsequent maize yields. Overall, these findings highlight that sustainable land management practices, together with institutional support through farmer organizations, play a crucial role in enhancing maize productivity and strengthening the resilience of smallholder farmers to climate change.

VI. Discussion

The findings indicate that land size, membership in farmers' organizations, contour farming, planting legumes, the use of organic fertilizer, and fallowing significantly enhance maize productivity, demonstrating the importance of resource availability, collective action, and sustainable land management in climate adaptation. Larger landholdings provide greater opportunities for adopting climate-smart agricultural practices, while farmer organizations improve access to extension services, knowledge, and production inputs, consistent with previous studies that emphasize the role of productive resources and institutional support in building resilience (Eyshi-Rezaei et al., 2023; Farooq et al., 2023; Neupane et al., 2022; Habib-ur-Rahman et al., 2022; Wang et al., 2023). Furthermore, sustainable practices such as contour farming, legume intercropping, organic fertilizer application, and fallowing significantly improve soil fertility, moisture retention, and yield stability, reinforcing evidence that conservation agriculture and indigenous land management practices are effective strategies for enhancing resilience and sustaining maize production under climate change (Rosa, 2022; Bibi & Rahman, 2023; Yu et al., 2022; Zhu et al., 2024; Farooq et al., 2023).

VII. Conclusion

The findings of this study provide strong empirical evidence that climate change adaptation strategies and institutional participation play a crucial role in enhancing maize productivity among smallholder farmers in Tanzania. The positive and statistically significant effects of land size, membership in farmers' organizations, and key adaptation practices such as contour farming, planting of legumes, use of organic fertilizers, and fallowing highlight the multidimensional nature of climate resilience in smallholder agriculture. Larger landholdings were associated with higher maize output, reflecting the importance of land access in enabling better resource management and sustainable farming practices. Similarly, farmers' organization membership emerged as a vital social asset, offering access to information, training, and collective resources that facilitate adoption of climate-smart practices. Among the specific adaptation measures, contour farming and legume intercropping demonstrated strong positive impacts on yields, validating the effectiveness of traditional and ecological soil management techniques in stabilizing productivity under erratic rainfall conditions. The use of organic fertilizers further highlighted the value of environmentally sustainable inputs that improve soil fertility, structure, and water retention factors essential for maintaining productivity amid increasing climate variability. Most notably, fallowing proved to be the most influential strategy, reaffirming the enduring relevance of indigenous knowledge systems in restoring soil health and maintaining long-term productivity. Overall, these results suggest that integrating both traditional and modern climate-smart practices, supported by farmer organizations and adequate land access, can substantially enhance smallholder farmers' adaptive capacity and productivity, thereby contributing to food security and sustainable agricultural development in the face of climate change.

Policy Implications

Policymakers should enhance climate resilience among smallholder farmers by strengthening land tenure security, improving equitable access to land, and promoting land consolidation, mechanization, and sustainable farming systems through effective implementation of the National Land Policy and Village Land Act. Strengthening farmer organizations through capacity building, extension services, financial literacy, and group-based credit schemes can improve knowledge sharing and adaptive capacity. Sustainable practices such as contour farming, legume intercropping, organic fertilizer use, and fallowing should be integrated into Tanzania's climate adaptation strategies and promoted through institutions such as TARI, NEMC, and local governments, while incorporating indigenous knowledge into extension and training programs. Furthermore, stronger coordination among agricultural, environmental, and water institutions, alongside increased investment in irrigation, soil conservation, digital advisory services, climate financing, and partnerships with development organizations, is essential for scaling up climate-smart agriculture and improving the productivity and resilience of smallholder farmers.

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