

Factors influencing farmers' climate adaptation strategies in major rice-growing regions in Tanzania

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ABSTRACT

Climate change increasingly threatens rice-based farming systems in Tanzania, where production is highly sensitive to water availability, labor constraints, and climate variability. This study examines the determinants and interrelationships of climate adaptation strategies among rice-farming households in major producing regions, Mbeya, Morogoro, and Shinyanga, using nationally representative cross-sectional data from 441 households drawn from the 2020/21 Tanzania National Panel Survey. Drawing on random utility theory, the multivariate probit model is applied to estimate adoption decisions jointly for six adaptation strategies: supplemental irrigation, improved resilient rice varieties, integrated soil fertility management (ISFM), integrated pest management (IPM), alternate wetting and drying (AWD), and engagement in non-farm economic activities (NFEA). The results show that adaptation decisions are interdependent, with significant complementarities among water-management strategies and between improved varieties and pest management. However, strategies are not uniformly complementary; instead, they exhibit tradeoffs driven by labor availability, farm size, institutional access, and market connectivity. Water-related strategies are strongly shaped by regional agro-hydrological conditions, particularly in Morogoro, while labor-intensive practices such as ISFM and AWD depend heavily on household labor endowments. Larger farms are more likely to adopt improved varieties and IPM, whereas smaller farms favor soil and water management practices. Institutional factors, especially access to extension services, climate and weather information, and membership in social unions, emerge as key enablers of adaptation. Engagement in non-farm activities functions largely as a substitute adaptation pathway, reflecting opportunity-driven diversification rather than distress responses. This study shows that climate adaptation among rice farmers in Tanzania is characterized by interdependent and context-specific strategy choices shaped by agroecological conditions, household resources, and institutional access. The findings highlight that effective adaptation depends not on blanket promotion of climate-smart practices but on aligning specific strategies with local water availability, labor endowments, farm scales, and market integration. Policies should therefore prioritize geographically targeted water investments, scale-differentiated adaptation packages, and stronger farmer organizations and extension systems. Such context-sensitive and institutionally grounded approaches are essential for enhancing adoption, efficiency, and resilience in Tanzania's rice sector.

Keywords: Climate Change Adaptation, Climate-Smart Agriculture, Rice Farming, Multivariate Probit, Tanzania

I. INTRODUCTION

Climate change is increasingly recognized as one of the most pressing global challenges, with far-reaching consequences for agricultural systems, rural livelihoods, and economic development. These impacts are particularly severe in developing countries, where agriculture remains highly climate-sensitive and provides the primary source of income and food security for rural households. In sub-Saharan Africa (SSA), rising temperatures, shifts in rainfall onset, and increased precipitation variability are already undermining agricultural productivity and increasing yield volatility, thereby heightening risks of food insecurity and poverty (Ojo & Baiyegunhi, 2020). At the global level, climate change is estimated to have reduced agricultural output growth by nearly 20 percent since the 1960s, underscoring the urgency of effective adaptation responses in climate-vulnerable regions (Ortiz *et al.*, 2021).

Adaptation has therefore emerged as a central pillar of agricultural resilience under climate change. It encompasses adjustments in production practices, resource allocation, and livelihood strategies aimed at reducing vulnerability to climate-related shocks and stabilizing farm outcomes under uncertainty (Intergovernmental Panel on Climate Change [IPCC], 2022; Badeke, 2023). In Tanzania, adaptation is embedded in national policy frameworks such as the National Climate Change Response Strategy 2021–2026 (United Republic of Tanzania [URT], 2021), which promotes practices including improved seed use, irrigation, planting date adjustments, soil and water conservation, and livelihood diversification. Empirical studies show that farmers employ a diverse portfolio of strategies, ranging from irrigation and pest management to the adoption of climate-resilient varieties, livestock integration, remittances, and non-farm activities (Muhie, 2022; Bongole, 2023; Gwambene & Saria, 2024). However, adoption remains uneven across

households and regions, reflecting differences in resource endowments, institutional access, and agro-ecological conditions.

While a growing body of literature examines the determinants of adaptation adoption, considerably less attention has been paid to whether adaptation strategies actually improve agricultural outcomes, and even less to how multiple strategies interact. Most studies implicitly assume that adopting more adaptation practices necessarily leads to better outcomes, overlooking the possibility that strategies may be either complementary or substitutable. From a theoretical perspective, complementarity arises when the effectiveness of one practice depends on the adoption of another, for example, when improved seed varieties require a reliable water supply to realize their yield potential (Teklewold *et al.*, 2019). Conversely, substitutability or diminishing marginal returns may occur when multiple practices compete for scarce resources such as labor, liquidity, or managerial capacity, thereby limiting the benefits of joint adoption (Mungai, 2020; Tadesse *et al.*, 2023). This ambiguity in adaptation logic represents a critical gap in the literature, particularly in smallholder systems characterized by binding constraints.

These issues are especially salient in rice-based production systems, which differ fundamentally from maize or mixed farming systems in ways that shape adaptation incentives and outcomes. Rice cultivation is highly sensitive to water availability and timing, relies on specific agro-hydrological conditions, and is more labor-intensive during key production stages such as transplanting and harvesting (Nakano *et al.*, 2018). Unlike maize, which is commonly grown in diversified rain-fed systems, rice is often cultivated in lowland or irrigated environments where climate risks are dominated by flooding, water control failures, and seasonal labor bottlenecks. Moreover, rice is relatively more commercialized, increasing farmers' exposure to price risk and liquidity constraints that influence their capacity to adopt and sustain adaptation practices (Nkuba *et al.*, 2021). These structural characteristics suggest that adaptation outcomes in rice systems are likely governed by a combination of risk-smoothing mechanisms, labor constraints, liquidity limitations, and agro-hydrological conditions, rather than by adaptation intensity alone.

In Tanzania, rice occupies a strategically important position in the agricultural economy. The crop contributes approximately 3 percent of GDP and supports the livelihoods of nearly two million people (Nkuba *et al.*, 2016). National rice production reached about 2.4 million metric tons in the 2023/24 season, with nearly half of the total output marketed, making rice more commercially significant than maize (URT, 2024). Despite this importance, average yields remain low at around 2.8 t/ha, compared with a national potential of 3.39 t/ha and a global average of 4.7 t/ha (Kulyakwave *et al.*, 2022). Climate change has been identified as a major contributor to this yield gap, intensifying production risks through erratic rainfall, flooding, and drought episodes in major rice-growing regions such as Morogoro, Mbeya, Shinyanga, and Mwanza (Nkuba *et al.*, 2021). These conditions make rice systems an especially relevant context for examining the effectiveness and interaction of adaptation strategies.

Empirical evidence from Tanzania and across SSA indicates that adaptation decisions are shaped by a complex interplay of socioeconomic, institutional, and environmental factors. Household characteristics such as education, age, and gender influence risk perception and adaptive capacity, while farm size and asset ownership increase the likelihood of adopting capital-intensive practices such as irrigation (Teklewold *et al.*, 2013; Brüssow *et al.*, 2017). Institutional factors, including access to extension services, climate information, credit, cooperatives, and secure land tenure, play a central role in enabling adaptation by relaxing liquidity and information constraints (Mongi *et al.*, 2010). Environmental conditions, particularly soil fertility and water availability, further determine the feasibility and effectiveness of specific strategies. Nevertheless, persistent barriers such as limited access to finance, weak extension delivery, and poor infrastructure continue to constrain effective adaptation, particularly among resource-poor households (World Bank, 2022; URT, 2023).

Despite this expanding literature, rice-specific evidence on adaptation effectiveness remains sparse and outdated. Most existing studies focus on general farming systems or examine adaptation adoption without assessing outcome-level impacts (Mkonda, 2021; Muhie, 2022). The only notable rice-focused study in Tanzania was conducted more than a decade ago and was limited to a district-level assessment (Balama *et al.*, 2013). Consequently, there is limited contemporary understanding of how rice farmers across major producing regions adapt to climate change, whether adopting multiple strategies yields superior outcomes relative to focused adoption, and which mechanisms dominate these outcomes.

Against this backdrop, the present study contributes to the literature in three key ways. First, it identifies the range of climate adaptation strategies adopted by rice-farming households, providing a comprehensive picture of how farmers respond to climate variability in rice-based systems. Second, it examines the interrelationships among the identified adaptation strategies through correlation analysis, assessing whether strategies are jointly adopted and whether they function as complements or substitutes under resource-constrained conditions. Third, it analyzes the factors influencing farmers' choice of specific adaptation strategies, with particular attention to household characteristics, resource endowments, and institutional and market conditions. Together, these contributions offer new empirical insights into the structure of adaptation decision-making and the contextual drivers shaping climate adaptation in rice production systems.

1.1 Statement of the Problem

In Tanzania, rice occupies a strategically important position in the agricultural economy, contributing approximately 3 percent of Gross Domestic Product [GDP] and supporting the livelihoods of nearly two million people (Nkuba *et al.*, 2016). National rice production reached about 2.4 million metric tons in the 2023/24 season, with nearly half of the total output marketed, making rice more commercially significant than maize (URT, 2024). Despite this importance, average yields remain low at around 2.8 t/ha well below the national potential of 3.39 t/ha and the global average of 4.7 t/ha with climate change identified as a major contributor to this persistent yield gap through increased rainfall variability, flooding, and drought episodes in key rice-growing regions such as Morogoro, Mbeya, Shinyanga, and Mwanza (Kulyakwave *et al.*, 2022; Nkuba *et al.*, 2021).

While empirical evidence from Tanzania and across sub-Saharan Africa shows that farmers respond to climate risks through a range of adaptation strategies shaped by socioeconomic characteristics, institutional access, and environmental conditions (Mongi *et al.*, 2010), persistent constraints related to finance, extension, and infrastructure continue to limit effective adaptation, particularly among resource-poor households (World Bank, 2022; URT, 2023). Despite this growing body of research, rice-specific evidence on climate adaptation in Tanzania remains sparse, outdated, and largely focused on adoption rather than effectiveness or interaction among strategies, with the only notable rice-focused study conducted more than a decade ago at a localized scale (Balama *et al.*, 2013; Mkonda, 2021; Muhie, 2022). As a result, there is limited contemporary understanding of how rice farmers across major producing regions adapt to climate change, how different adaptation strategies interact under resource constraints, and which factors most strongly shape farmers' adaptation choices, representing a critical gap for evidence-based and context-specific policy design.

1.2 Research Objective

The main objective of this study is to examine factors influencing climate adaptation strategies among rice-farming households in Tanzania by specifically identifying the range of adaptation practices adopted, analyzing the interrelationships among these strategies, and assessing the socioeconomic, institutional, and market factors that influence farmers' choice of specific adaptation options.

1.3 Research questions

This study is guided by the following research questions:

- (i) What climate adaptation strategies are adopted by rice-farming households across major rice-producing regions of Tanzania?
- (ii) To what extent are these adaptation strategies jointly adopted?
- (iii) What socioeconomic, institutional, and market factors determine farmers' choice of specific climate adaptation strategies?

II. THEORETICAL FRAMEWORK

Random Utility Theory (RUT) constitutes the core analytical framework of the study. The theory posits that individuals derive utility from each available alternative and choose the option that yields the highest utility. Because utility is only partially observable, it is decomposed into a systematic component that captures the observable characteristics of the individual, farm, and institutional environment, and a random component representing unobserved preferences, expectations, and information constraints (Falmagne, 1978).

This formulation allows adaptation decisions to be modelled probabilistically rather than deterministically. So, applying to climate adaptation, RUT conceptualizes adaptation as a choice-based process under uncertainty, where rice farmers evaluate alternative strategies, such as varietal change, adjustment of planting dates, water management practices, or livelihood diversification, based on expected benefits, implementation costs, risk-reducing potential, and available resources. Variations in socio-economic characteristics, institutional access, and perceived climate risks systematically influence the utility associated with each adaptation option, thereby shaping observed choice patterns.

III. METHODOLOGY

3.1 Research Design

This study employs a cross-sectional research design using data from the Tanzania National Panel Survey (NPS) Wave 5 (2020/21). Although the NPS is a longitudinal survey, the analysis utilizes the cross-sectional component of Wave 5 to examine climate adaptation strategies among rice-farming households across major rice-producing regions. The cross-sectional design is suitable for this study because it captures farmers' adaptation decisions and associated socioeconomic, institutional, and environmental conditions at a common point in time, allowing for systematic

comparison of adaptation choices across households and regions. Given the study's objective of identifying adaptation strategies, assessing their interrelationships, and analyzing the factors influencing farmers' choices, the cross-sectional approach provides an appropriate and efficient framework for modeling joint adoption behavior using multivariate probit techniques, while maintaining national representativeness.

3.2 Study Area

The study was conducted in three major rice-producing regions of Tanzania, namely Shinyanga, Morogoro, and Mbeya, selected to represent different agroecological zones and production systems. Shinyanga lies in the northwestern semi-arid zone, receiving 600–800 mm of annual rainfall with predominantly rainfed lowland rice systems. Frequent droughts and erratic rainfall make it highly vulnerable to climate variability (URT, 2022). Morogoro, located in eastern Tanzania, experiences a tropical bimodal climate with 800–1,200 mm of rainfall per year. Fertile alluvial plains in districts such as Kilombero and Mvomero support both rainfed and irrigated rice production, though flooding and pest outbreaks remain common (Nakano et al., 2018). Mbeya, in the southern highlands, has a humid highland climate with 1,000–2,500 mm of rainfall. The region's major rice zones, including Mbarali and Kyela, benefit from extensive irrigation but face challenges such as seasonal floods and soil degradation (Kulyakwave et al., 2022). These regions capture Tanzania's key rice agroecological systems: semi-arid, tropical lowland, and humid highland, providing a representative basis for analyzing climate adaptation among rice farmers.

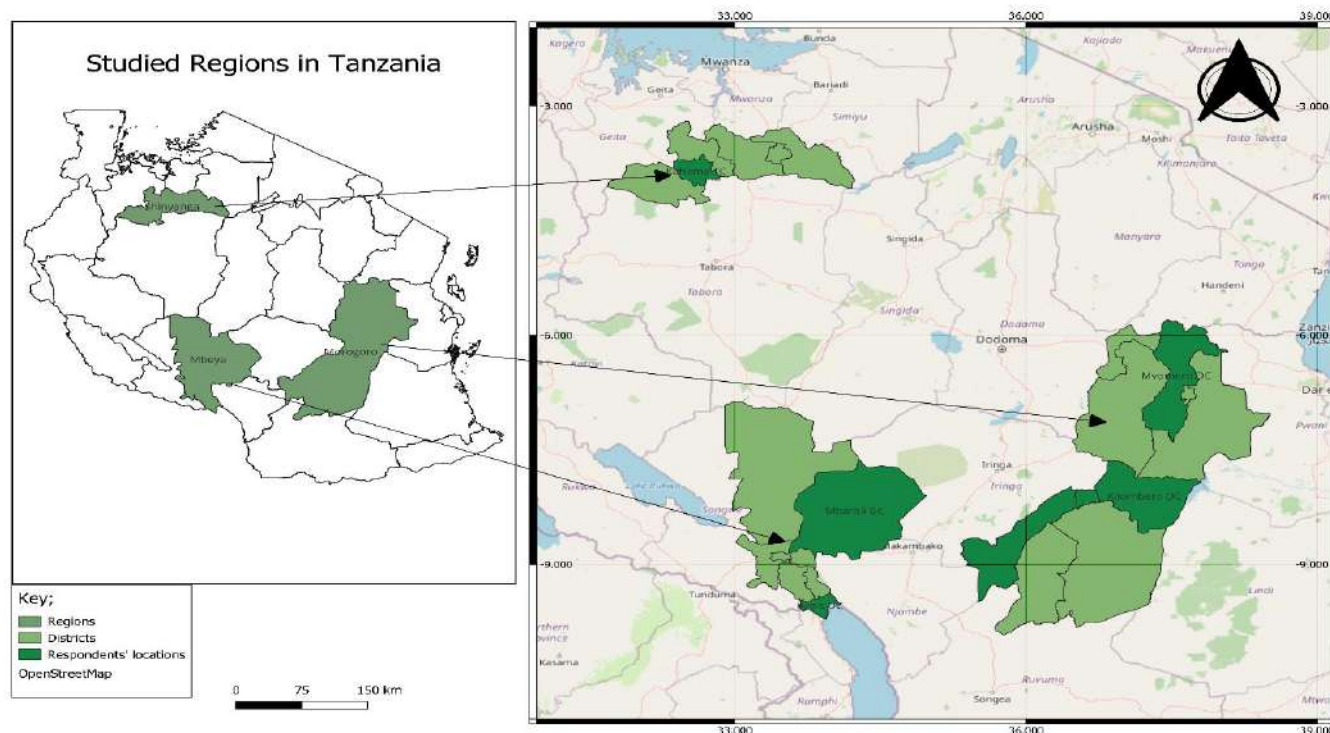


Figure 1
Map Describing the Spread of Respondents' Location (QGIS, 2025)

3.3 Target population

The target population of this study consists of rice-farming households in Tanzania. Using data from the Tanzania National Panel Survey (NPS) Wave 5 (2020/21), the analysis focuses on households that reported rice cultivation during the reference agricultural season. This subpopulation represents rice producers operating under diverse agroecological, institutional, and market conditions, and the nationally representative design of the NPS allows the findings to be generalized to rice-farming households across Tanzania.

3.4 Sampling Procedures and Sample Size

This study utilized a sample of 441 rice-farming households drawn from the Tanzania National Panel Survey (NPS) Wave 5 (2020/21). The NPS employed a two-stage stratified random sampling design, ensuring representativeness across Tanzania's rural and urban locations. In the first stage, enumeration areas were randomly selected from the National Bureau of Statistics (NBS) master sampling frame, while in the second stage, households were randomly chosen within each enumeration location for the interview. From this nationally representative dataset, a subsample was extracted focusing exclusively on households engaged in rice cultivation in three major producing regions, namely, Shinyanga, Morogoro, and Mbeya. These regions were intentionally selected to capture variation across

distinct agroecological zones, ranging from semi-arid lowlands (Shinyanga), tropical lowlands (Morogoro), to highland areas (Mbeya). This regional diversity allows for meaningful comparison of adaptation behaviors under different climatic and production conditions. According to Long and Freese (2014), a minimum of 10–15 observations per parameter is generally sufficient to ensure reliable coefficient estimation and model convergence in multivariate models. The final analytical sample consisted of 441 respondents; a size considered statistically sufficient for multivariate analysis, such as the Multivariate Probit (MVP) model applied in this study. The sample provides adequate variation across socio-economic, demographic, and agroecological characteristics, ensuring reliable parameter estimation and enhancing the robustness and generalizability of the findings. Furthermore, this sample aligns with comparable studies on smallholder adaptation and technology adoption in Tanzania (Ojo and Baiyegunhi, 2020; Onyeneke, 2021).

3.5 Data and Data Source

This study draws on secondary data from the Tanzania National Panel Survey (NPS) Wave 5 (2020/21), focusing on household heads engaged in rice cultivation across the country's major producing regions, namely Morogoro, Mbeya, and Shinyanga. The survey, implemented by the National Bureau of Statistics (NBS), was designed to track national and international development indicators, analyze poverty dynamics, assess the role of smallholder agriculture in household welfare, and evaluate policy outcomes. The dataset provides detailed information on farmers' demographic and socio-economic characteristics, income sources, rice production, and adaptation practices. Climate adaptation strategies were captured as binary indicators, taking the value of 1 when a farmer reported using an adaptation strategy and 0 otherwise. Although the NPS Wave 5 dataset is a reliable and nationally representative source of information on household welfare and agricultural practices, certain limitations should be acknowledged. Key variables such as yields, input use, and income are self-reported, which introduces potential recall bias and reporting errors. Moreover, some households have incomplete records, particularly regarding income and yield data, necessitating imputation procedures. Despite these challenges, the NPS remains one of the most comprehensive and credible data sources for examining agricultural households in Tanzania, offering a robust foundation for policy-relevant empirical research.

3.6 Data Analysis

Identification of climate adaptation strategies used in rice production in Tanzania: Farmers were asked to share their perceptions of climate changes over the past ten years and to report how often they had faced risks such as droughts, floods, crop pests, diseases, and other livelihood shocks. Drawing from these experiences, they were then asked to identify the strategies they had recently applied to cope with such risks. In line with existing literature on climate change adaptation, the most common practices mentioned included the use of drought-tolerant crop varieties, supplemental irrigation, pest- and disease-resistant varieties, crop diversification, and soil and Alternate Wetting and Drying. Descriptive statistical methods were then employed to describe climate adaptation strategies in rice production in surveyed areas. Specifically, frequency and percentage analyses were made to identify the proportion of various adaptation strategies adopted by rice farmers. These strategies described here were considered as outcome variables in the multivariate probit analysis.

Assessment of factors that influence the choice of climate adaptation strategies among rice farmers in Tanzania: This study employed a Multivariate Probit (MVP) model to analyze the determinants of rice farmers' adoption of climate adaptation strategies in Tanzania. Following the approaches of Ojo and Baiyegunhi (2020) and Diro (2022), the MVP model was considered suitable because it captures the likelihood that farmers adopt several strategies at the same time. It recognizes that the choice of one adaptation practice may be related to the decision to adopt others, reflecting the interconnected nature of farmers' responses to climate risks. By doing so, the model generates consistent and efficient estimates, offering more comprehensive insights into the factors shaping farmers' adaptation choices. The model is thus expressed as follows:

$$Y_i = 1 \text{ when } \beta_i X' + \varepsilon_i > 0$$

$$Y_i = 0 \text{ when } \beta_i X' + \varepsilon_i \leq 0, i = 1, 2 \dots 5$$

Where; in this model, x denotes the vector of explanatory variables, while $\beta_1, \beta_2, \beta_3, \beta_4,$ and β_5 represent the corresponding parameter vectors. The error terms $\varepsilon_1, \varepsilon_2, \varepsilon_3, \varepsilon_4,$ and ε_5 are assumed to follow a multivariate normal distribution with a mean of zero, unit variance, and an $n \times n$ correlation matrix

IV. FINDINGS & DISCUSSION

4.1 Descriptive Statistics and Interpretation

The descriptive results presented in Table 1 show that the majority of farmers (79%) own the land they cultivate, indicating high tenure security, which may encourage long-term adaptation investments. About 31% of the farms are located on steep slopes, while the rest are on gentle terrains, implying that erosion risks may be limited to a smaller proportion of households. The average land size under cultivation is 4.52 acres (SD = 3.85), reflecting a predominance of small to medium-scale farmers with notable variability in farm sizes across households. Regarding household

characteristics, 54% of the respondents are male-headed households, suggesting a slightly male-dominated agricultural decision-making structure. The average age of household heads is 34.2 years (SD = 17.7), indicating that the majority of farmers are within a productive age bracket, though with considerable variation across age groups. The average household size is 5.6 members (SD = 3.8), suggesting the presence of adequate family labor that can be mobilized for farming and adaptation activities. On average, household heads have completed 8.6 years of schooling (SD = 2.7), corresponding roughly to a full primary education, which may enhance their capacity to comprehend and adopt new agricultural technologies. The average distance to the nearest market is 2.65 km (SD = 1.93), implying relatively good market accessibility for most farmers.

Table 1
Descriptive Statistics on the Variables Used in Advanced Analyses

Variables	Description	Mean	Std. Dev.
Explanatory Variables			
Farm features			
Slope of the farm	Dummy where 0=Gentle, 1=Steep	0.31	0.19
Land tenure	Dummy where 1=Owned, otherwise=0	0.79	0.33
Size of land in use	Number of acres in use for farming	4.52	3.85
Farming household characteristics			
Gender	Dummy where 1=male, female=0	0.54	0.30
Age	Number of years of household head since birthdate	34.23	17.71
Household size	Number of members in the surveyed household	5.64	3.82
Education	Number of years spent by HH head in schooling	8.56	2.67
Distance to nearby market	Number of kilometers from storing point to the nearby market	2.65	1.93
Off-farm income	Dummy if household generates income off-farm =1, otherwise=0	0.65	0.55
Climate risk experience	Dummy if household experience climate related risks for the past 5 years=1, otherwise=0	0.74	0.47
Membership to social unions	Dummy if any household member has membership=1, otherwise=0	0.39	0.40
Credit support for farming	Dummy if household had a credit support=1, otherwise=0	0.46	0.33
Access to extension from government	Dummy if household receives government extension service=1, otherwise=0	0.53	0.44
Access to extension delivered through radio/TV	Dummy if household accessed the services=1, otherwise=0	0.60	0.35
Access to climate & weather information	Dummy if household accessed the services=1, otherwise=0	0.48	0.51
Explained (dependent) Variables			
Supplemental irrigation	Dummy if household practices supplemental irrigation as an adaptation strategy=1, otherwise=0	0.23	0.39
Improved resilient varieties	Dummy if household uses as resilient varieties as an adaptation strategy=1, otherwise=0	0.29	0.40
Integrated Soil Fertility Management (ISFM)	Dummy if household practices ISFM as an adaptation strategy=1, otherwise=0	0.36	0.44
IPM	Dummy if household practices IPM as an adaptation strategy=1, otherwise=0	0.18	0.17
Alternate Wetting and Drying	Dummy if household practices AWD as an adaptation strategy=1, otherwise=0	0.36	0.43
Engagement in non-farm economic activities (NFEA)	Dummy if household practices NFEA as an adaptation strategy=1, otherwise=0	0.38	0.27

Next to that, approximately 65% of the households reported earning off-farm income, showing a high level of livelihood diversification beyond agriculture. Moreover, a substantial 74% of households experienced climate-related risks in the past five years, confirming widespread exposure to climatic variability. About 39% of the respondents are members of social unions or farmer groups, which may facilitate information sharing and collective action. Nearly half (46%) of the farmers accessed credit services, suggesting moderate financial inclusion levels. Access to extension services is fairly balanced: 53% received government extension services, while 60% accessed agricultural information through radio or television. Access to climate and weather information was reported by 48% of households, indicating that slightly more than half still lack timely climate advisories.

Concerning adaptation practices, the results show that 23% of households practiced supplemental irrigation, and 29% used improved resilient varieties, reflecting relatively low adoption of input- and capital-intensive practices. Integrated Soil Fertility Management (ISFM) and Alternate Wetting and Drying (AWD) were practiced by 36% of households each, suggesting that these agronomic and water-saving practices are gaining traction among farmers. However, adoption of Integrated Pest Management (IPM) remains low at only 18%, likely due to limited technical knowledge or extension support. Engagement in non-farm economic activities (NFEA) was reported by 38% of households, underscoring its importance as a complementary adaptation and income-smoothing strategy.

4.1.1 Interrelationships between the Climate Adaptive Strategies

The correlation results presented in Table 2 reveal varying degrees of relationships among the different climate adaptation strategies practiced by farming households. Most coefficients here are positive, implying that the adoption of one adaptation strategy tends to go with the adoption of others. This suggests that farmers often employ a combination of complementary measures to cope with and adapt to climatic stresses rather than relying on a single strategy.

A strong and statistically significant positive relationship was observed between Supplemental Irrigation and Alternate Wetting and Drying ($r = 0.388$, $p < 0.05$). This indicates that farmers who use supplemental irrigation are also more likely to apply the AWD technique. Both practices relate to improved water management and reflect a tendency for farmers with access to water resources to implement multiple water-saving technologies concurrently. Similarly, the correlation between Improved Resilient Varieties and Integrated Pest Management ($r = 0.317$, $p < 0.05$) was positive and significant, suggesting that farmers using improved seed varieties are also more likely to adopt pest management practices. This combination highlights an integrated approach where households combine genetic and agronomic measures to minimize yield losses under changing climatic conditions.

Another significant association emerged between Improved Resilient Varieties and Non-Farm Economic Activities ($r = 0.350$, $p < 0.05$). This relationship implies that households adopting resilient varieties also tend to diversify their livelihoods into non-farm activities. Such diversification may help to spread risk and enhance income stability, enabling households to invest in improved agricultural inputs and technologies. Other correlations, such as between Supplemental Irrigation and Improved Varieties ($r = 0.181$), Supplemental Irrigation and NFEA ($r = 0.271$), and ISFM with NFEA ($r = 0.232$) were positive but statistically insignificant, indicating a weak tendency toward joint adoption that may depend on specific household conditions or institutional support.

In contrast, almost negligible correlations were observed between Supplemental Irrigation and ISFM ($r = 0.021$), ISFM and IPM ($r = 0.009$), and AWD and NFEA ($r = 0.007$). These results suggest that these strategies are largely adopted independently rather than in combination. Such independence may arise from differences in resource requirements, technical knowledge, or external support needed for each practice. Overall, the correlation analysis indicates that while some adaptation strategies are complementary, particularly those related to water management and input use others operate more as stand-alone options. The observed positive associations reflect farmers' tendency to adopt integrated adaptation bundles that combine agronomic, technological, and livelihood diversification strategies to reduce vulnerability and build resilience to climate risks.

Table 2

Estimates from Correlation Analyses for the Regressands

<i>Explained Variables (dependent)</i>	Supplemental irrigation	Improved resilient varieties	ISFM	IPM	AW&D	NFEA
Supplemental irrigation	-	0.181	0.021	0.179	0.388**	0.271
Improved resilient rice varieties	0.181	-	0.166	0.317**	0.130	0.350**
Integrated Soil Fertility Management (ISFM)	0.021	0.166	-	0.009	0.102	0.232
IPM	0.182	0.317**	0.009	-	0.187	0.347**
Alternate Wetting and Drying (AW&D)	0.388**	0.130	0.102	0.187	-	0.007
Engagement in non-farm economic activities (NFEA)	0.271	0.350**	0.232	0.347**	0.007	-

**Statistically significant at 0.05 probability levels.

4.1.2 Determinants for Adaptation of Climate Strategies among Rice Farmers in Major Producing Locations

The average marginal effects (AMEs) from the multivariate probit model provide direct estimates of how each explanatory variable changes the probability of adopting specific climate-smart agriculture (CSA) strategies, expressed in percentage points and accounting for interdependence across choices. This framework allows not only identification

of statistically significant drivers but also assessment of their substantive relevance and the extent to which adaptation strategies function as complements or substitutes within rice-based farming systems.

Table 3

The Estimates (Average marginal effects) from Multivariate Probit (MVP) Regression

Variable (adaptation strategies)	Supplemental Irrigation	Improved Resilient Rice Varieties	Integrated Soil Fertility Management	Integrated Pest Management	Engagement in Non-Farm Activities	Alternate Wetting and Drying (AWD)
Age in years	0.008** (0.003)	0.012* (0.006)	0.005 (0.004)	0.009* (0.005)	-0.007 (0.005)	0.010** (0.004)
Sex (Male = 1)	-0.045* (0.025)	-0.032 (0.028)	-0.058** (0.026)	-0.041* (0.024)	0.062** (0.029)	0.071** (0.032)
Region residing (Mbeya)	0.052* (0.028)	0.085*** (0.031)	0.043 (0.027)	0.064** (0.029)	0.040 (0.026)	0.022 (0.025)
Morogoro	0.135*** (0.034)	0.039* (0.023)	0.024 (0.021)	0.089** (0.035)	0.154*** (0.038)	0.046* (0.027)
Education years	0.074** (0.032)	0.035* (0.019)	0.046** (0.021)	0.071*** (0.025)	0.096*** (0.030)	0.077** (0.034)
Household size	0.022 (0.015)	0.029* (0.016)	0.135*** (0.041)	0.090** (0.038)	0.047** (0.022)	0.158*** (0.047)
Farm size	-0.061** (0.028)	0.141*** (0.045)	-0.086** (0.034)	0.174*** (0.052)	0.112** (0.049)	-0.076** (0.031)
Slope of the farm (Gentle)	0.090** (0.037)	0.018 (0.022)	0.062** (0.029)	0.025 (0.021)	0.020 (0.018)	-0.029* (0.017)
Climate risk experience	0.049** (0.022)	0.033* (0.019)	0.071*** (0.025)	-0.020 (0.018)	-0.052* (0.028)	0.032* (0.019)
Membership to social unions	0.021 (0.018)	0.160*** (0.048)	0.039* (0.023)	0.055** (0.026)	0.027 (0.020)	0.016 (0.015)
Access to Extension (government)	0.044* (0.024)	0.033* (0.019)	0.053** (0.025)	0.017 (0.016)	-0.023 (0.019)	0.062** (0.028)
Access to extension (radio/TV)	0.054** (0.026)	0.028* (0.016)	0.018 (0.015)	0.138*** (0.042)	0.053* (0.028)	0.033* (0.019)
Access to climate & weather info	0.019* (0.011)	0.034** (0.017)	0.034* (0.018)	0.060** (0.027)	0.021 (0.014)	0.027* (0.016)
Nearby Market distance	-0.052* (0.028)	-0.042 (0.025)	-0.020 (0.016)	-0.161*** (0.049)	0.055** (0.026)	-0.035 (0.021)
Credit support for farming	0.040* (0.023)	0.055** (0.027)	0.042* (0.024)	0.075** (0.033)	-0.037* (0.021)	0.027 (0.018)
Wald chi ² (70)	533.31					
Prob>chi ²	0.000***					
Log Likelihood	-352.26					

***, **, and * statistically significant at 0.01, 0.05 and 0.1 probability levels. Values given in the parentheses are standard errors.

For supplemental irrigation, several drivers exhibit economically meaningful effects rather than merely statistical significance. Regional location dominates other covariates: residence in Morogoro increases adoption probability by 13.5 percentage points, an effect size substantially larger than those associated with age (0.8 percentage points per year) or climate risk experience (4.9 percentage points). This highlights that irrigation adoption in rice systems is primarily governed by agro-hydrological and infrastructural conditions rather than household characteristics alone, consistent with evidence that water control is highly location-specific in paddy systems (Nakano et al., 2018; Nkuba et al., 2021). The negative effect of farm size (-6.1 percentage points) challenges the conventional assumption that larger farms are more likely to invest in irrigation. In rice systems, expanding irrigation over larger plots substantially increases capital and management costs, making irrigation more attractive for smaller, intensively managed farms. This contrasts with maize-based systems, where irrigation often scales more smoothly with land size (Arouna et al., 2023).

Adoption of improved resilient rice varieties is most strongly influenced by social and institutional mechanisms rather than demographic factors. Membership in social unions raises adoption probability by a striking 16.0 percentage

points, the single largest effect in the entire model, dwarfing the marginal impacts of age (1.2 percentage points) and education (3.5 percentage points). This finding underscores the centrality of collective action and informal seed networks in rice systems, where access to certified or stress-tolerant seed is often mediated through cooperatives rather than markets (Fischer & Qaim, 2022). Farm size also exerts a large positive effect (14.1 percentage points), suggesting that improved varieties exhibit complementarities with scale, unlike irrigation or soil fertility management. This heterogeneity across strategies provides clear evidence against the assumption that CSA technologies form a universally complementary bundle.

Integrated soil fertility management (ISFM) displays a distinct labor-driven adoption pattern. Household size has a substantively large effect, increasing adoption probability by 13.5 percentage points, far exceeding the effects of education or extension access. This reflects the labour-intensive nature of ISFM practices such as manure application and residue management, which are particularly demanding in flooded rice fields (Teklewold et al., 2019). The negative effect of farm size (−8.6 percentage points) further indicates scale-related constraints, suggesting that ISFM is more feasible on smaller plots where labor can be concentrated. The lower likelihood of adoption among male-headed households (−5.8 percentage points) is notable and somewhat counterintuitive, as men are often assumed to be early adopters of agricultural technologies. In rice systems, however, soil fertility practices are frequently embedded in women’s management roles, particularly where organic inputs and plot-level decisions are concerned (Doss et al., 2018).

Integrated pest management (IPM) is driven primarily by information and market-related mechanisms. Access to radio or television extension increases adoption probability by 13.8 percentage points, a substantively large effect that exceeds those of formal extension or education. This highlights the technical and knowledge-intensive nature of IPM, which relies on timely information and pest diagnostics rather than capital inputs alone (Barrett et al., 2022). Farm size again shows a strong positive association (17.4 percentage points), suggesting that IPM generates increasing returns with scale due to cost spreading and commercial orientation. Conversely, a greater distance to markets reduces adoption by 16.1 percentage points, one of the largest negative effects observed, indicating that IPM is closely tied to market access, where pest control protects output quality and saleability. This market dependence differentiates IPM from soil- and water-based strategies that primarily target production stability.

Engagement in non-farm activities exhibits a different adaptation logic, functioning largely as a substitute rather than a complement to on-farm strategies. Education (9.6 percentage points), Morogoro residence (15.4 percentage points), and male headship (6.2 percentage points) exert economically meaningful effects, reflecting mobility, skills, and access to off-farm opportunities. Importantly, access to credit reduces the probability of non-farm engagement by 3.7 percentage points, suggesting that liquidity enables farmers to reinvest in agricultural adaptation rather than diversify out of farming. This finding challenges the common narrative that credit universally promotes diversification and instead supports the view that financial access shapes the direction of adaptation choices (Di Falco & Veronesi, 2013).

Adoption of alternate wetting and drying (AWD) is most strongly influenced by household labor availability and information access. Household size increases adoption probability by 15.8 percentage points, the largest effect for AWD, reflecting the labor demands associated with monitoring and timing irrigation cycles. Education (7.7 percentage points) and government extension (6.2 percentage points) also have substantively important effects, consistent with the technical precision required for AWD implementation (Lampayan et al., 2015). The negative effect of gentle slopes (−2.9 percentage points) appears small in magnitude and, while statistically significant, is economically modest relative to other drivers. This distinction illustrates the importance of not over-interpreting statistically significant but substantively minor effects. The positive effect of male headship (7.1 percentage points) contrasts with patterns observed for soil fertility and irrigation, indicating that gender effects are strategy-specific rather than uniform.

Taken together, these results demonstrate that adaptation strategies in Tanzanian rice systems are not uniformly complementary. Instead, farmers reallocate effort across strategies in response to labor constraints, liquidity, information access, and agro-hydrological conditions. Large effect sizes associated with region, household size, farm size, social networks, and extension access dominate marginal demographic effects such as age, underscoring the importance of structural and institutional factors. These findings provide new empirical evidence that rice systems generate adaptation incentives distinct from maize or mixed farming systems, where water control, labor timing, and plot-level management play a more central role. By explicitly comparing effect sizes across strategies and distinguishing between statistically significant but economically trivial effects and those with substantive importance, the analysis strengthens causal interpretation while remaining appropriately cautious.

4.2 Discussion

The results provide robust evidence that climate adaptation among rice farmers in Tanzania is shaped by a complex interaction of agro-hydrological conditions, labor availability, institutional access, and market incentives, rather than by household characteristics alone. The strong joint significance of the multivariate probit model confirms that adaptation strategies are interdependent, justifying the use of a joint adoption framework and reinforcing the argument that farmers respond to climate risks by reallocating effort across multiple pathways rather than selecting a single

dominant strategy. This finding aligns with emerging evidence that climate adaptation decisions are best understood as portfolio choices under risk and resource constraints (Di Falco & Veronesi, 2013; Teklewold et al., 2019).

One of the most salient findings is the dominant role of regional location in shaping adaptation behavior, particularly for water-related strategies. The substantially higher probability of adopting supplemental irrigation and AWD among farmers in Morogoro highlights the primacy of agro-hydrological endowments and infrastructure in rice systems. Unlike maize or mixed cropping systems, rice cultivation is inherently water-intensive and highly sensitive to water timing and control, making adaptation returns strongly location-specific (Nakano et al., 2018; Nkuba et al., 2021). This spatial heterogeneity suggests that uniform national adaptation policies may be inefficient and underscores the need for regionally differentiated interventions that reflect local hydrology and institutional capacity.

The analysis also challenges conventional assumptions regarding farm size and adaptation. While larger farm size increases the likelihood of adopting improved resilient varieties and IPM strategies that benefit from scale economies and market orientation, it significantly reduces the probability of adopting supplemental irrigation, ISFM, and AWD. This pattern indicates that adaptation strategies are not universally complementary; instead, they exhibit strategy-specific scale effects. In rice systems, expanding irrigation or labor-intensive soil practices over larger plots substantially raises costs and management complexity, making these strategies more attractive to smaller, intensively managed farms. This finding contrasts with evidence from upland cereal systems, where larger farms often exhibit higher adoption of capital-intensive technologies (Arouna et al., 2023; Geja & Maphosa, 2023), and provides new insight into the scale-dependent nature of adaptation in irrigated and semi-irrigated rice ecologies.

Labor availability emerges as a central mechanism shaping adaptation choices. Household size exerts some of the largest marginal effects in the model, particularly for ISFM and AWD, both of which require timely and coordinated labor inputs. This highlights labor constraints as a binding factor in rice-based adaptation, where practices such as organic soil amendment and controlled irrigation depend on household labor rather than mechanization. Similar labor-driven adoption patterns have been observed in rice systems in Asia and East Africa, where household labor availability conditions the feasibility of climate-smart practices (Lampayan et al., 2015). These results reinforce the importance of considering labor dynamics when promoting adaptation technologies, particularly in smallholder-dominated systems.

Gender effects in the results are notably heterogeneous and challenge the assumption that male-headed households are uniformly more likely to adopt agricultural technologies. Male headship reduces the likelihood of adopting supplemental irrigation and ISFM but increases engagement in non-farm activities and AWD. This pattern suggests that gender shapes not the intensity but the direction of adaptation. In rice systems, women often play a central role in plot-level management and soil fertility practices, while men may prioritize strategies that either reduce labor burdens or diversify income sources. These findings are consistent with gender-differentiated roles in African agriculture and highlight the risk of overlooking women's contribution to climate adaptation if interventions are not gender-sensitive (Doss et al., 2018; Awoke et al., 2025).

Institutional access, particularly social networks and information channels emerge as one of the most powerful drivers of adaptation. Membership in social unions has the single largest effect on adoption of improved resilient rice varieties, underscoring the importance of collective action and informal seed systems in contexts where formal markets may be thin or unreliable. Similarly, access to extension services delivered through radio and television has a substantively large effect on IPM adoption, reflecting the knowledge-intensive nature of pest management practices. These results suggest that information dissemination mechanisms may be more effective than traditional extension alone for complex technologies, corroborating evidence that mass media can play a critical role in scaling climate-smart agriculture (Fischer & Qaim, 2022; Barrett et al., 2022).

Market access further differentiates adaptation strategies. The strong negative association between distance to markets and IPM adoption indicates that pest management is closely tied to commercialization incentives, where maintaining grain quality is essential for market participation. In contrast, market distance has weaker or insignificant effects on soil and water management practices, which primarily stabilize production rather than enhance market returns. This distinction highlights that adaptation strategies serve different economic objectives some prioritize yield stability and risk reduction, while others are linked to output quality and commercialization. Such differentiation is often overlooked in adaptation studies that treat technologies as homogeneous responses to climate risk (Kassie et al., 2015).

Engagement in non-farm economic activities operates largely as a substitute adaptation pathway. Education, male headship, and regional location strongly increase the likelihood of off-farm engagement, while access to credit reduces it, suggesting that liquidity enables households to intensify on-farm adaptation rather than diversify away from agriculture. This finding refines the prevailing narrative that diversification is always a response to constraint, instead indicating that non-farm activities may reflect opportunity-driven adaptation among households with greater human capital and mobility. Similar substitution dynamics between farm and non-farm adaptation have been observed in other Sub-Saharan African contexts (Di Falco & Veronesi, 2013; Bezu & Barrett, 2012).

Overall, the discussion demonstrates that adaptation in Tanzanian rice systems is neither uniformly complementary nor uniformly constrained. Instead, farmers make context-specific trade-offs shaped by water control, labor availability, liquidity, information access, and market incentives. By explicitly comparing effect sizes across

strategies and distinguishing between statistically significant but economically modest effects and those with substantive importance, the analysis advances understanding of how and why adaptation pathways differ within rice-based systems. These insights contribute new empirical evidence to the adaptation literature by showing that rice systems generate distinct incentives relative to maize or mixed farming systems, reinforcing the need for tailored, strategy-specific adaptation policies rather than one-size-fits-all solutions.

V. CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

This study provides comprehensive empirical evidence on the patterns, interrelationships, and determinants of climate adaptation strategies among rice-farming households in major rice-producing regions of Tanzania. Using nationally representative data and a multivariate probit framework, the analysis demonstrates that rice farmers respond to climate variability through a diverse portfolio of strategies rather than relying on a single adaptation pathway. The strong joint significance and observed correlations among strategies confirm that adaptation decisions are interdependent, validating the need for analytical approaches that explicitly account for simultaneous adoption. The findings reveal substantial heterogeneity in adaptation behavior across regions, farm sizes, and household characteristics, underscoring that adaptation in rice systems is highly context-specific. Water-related strategies such as supplemental irrigation and alternate wetting and drying are strongly shaped by agro-hydrological conditions and regional infrastructure, while soil fertility management and AWD are primarily constrained by household labor availability. Improved resilient varieties and integrated pest management display scale and market orientation effects, benefiting larger and more commercially connected farms. These patterns provide clear evidence that climate adaptation strategies are neither uniformly complementary nor universally scalable, but instead involve trade-offs shaped by labor, liquidity, information, and market access. Institutional and informational factors emerge as particularly powerful drivers of adaptation. Access to extension services, climate and weather information, and especially membership in social unions significantly increases the likelihood of adopting key strategies, highlighting the central role of collective action and knowledge dissemination in overcoming adoption barriers. At the same time, engagement in non-farm economic activities functions largely as a substitute adaptation pathway, reflecting opportunity-driven diversification rather than purely distress responses. Gender effects are found to be strategy-specific, indicating that men and women participate differently across adaptation options, with important implications for inclusive policy design. Overall, the study advances the climate adaptation literature by providing rice-specific evidence that challenges generalized assumptions derived from maize or mixed farming systems. It demonstrates that effective adaptation in rice-based systems depends less on the number of strategies adopted and more on aligning specific practices with local agroecological conditions, household resource constraints, and institutional environments. These insights emphasize that climate adaptation policies in Tanzania's rice sector should move beyond one-size-fits-all approaches toward targeted, scale-sensitive, and institutionally grounded interventions that recognize the differentiated incentives and constraints faced by smallholder farmers.

5.2 Recommendations

Effective climate adaptation in Tanzania's rice sector requires a shift away from uniform promotion of climate-smart agriculture toward context-specific and targeted interventions. Water-related strategies such as supplemental irrigation and alternate wetting and drying (AWD) should be geographically targeted to areas with suitable agro-hydrological conditions and existing infrastructure, particularly in regions like Morogoro, to improve cost-effectiveness and avoid low adoption in unsuitable areas.

Labor constraints significantly limit the adoption of labor-intensive practices such as integrated soil fertility management (ISFM) and AWD. Adaptation policies should therefore align promoted practices with household labor endowments and integrate labor-saving technologies, collective labor arrangements, or coordinated implementation at the scheme or village level, especially in rice systems with tight production calendars.

Farm size heterogeneity calls for scale-differentiated adaptation packages. Larger farms are more likely to adopt improved resilient varieties and integrated pest management (IPM), while smaller farms favor soil and water management practices. Policies should accordingly prioritize seed systems and IPM for commercially oriented farms, and ISFM, AWD, and small-scale irrigation for smallholders, avoiding one-size-fits-all approaches.

Institutional mechanisms are critical for accelerating adoption. Strengthening farmer organizations, cooperatives, and group-based seed systems is essential for scaling resilient varieties, while mass-media and digital extension should be expanded for knowledge-intensive practices such as IPM, where they outperform conventional extension.

Market access shapes adaptation incentives unevenly. IPM adoption depends strongly on proximity to markets, implying that promotion in remote areas must be paired with investments in market infrastructure and aggregation

systems. In contrast, soil and water management practices are better suited to less commercialized zones, underscoring the need for policy sequencing.

Engagement in non-farm activities functions as an alternative adaptation pathway driven by human capital rather than distress. Coordinated agricultural finance and rural enterprise development are needed to prevent unintended substitution away from productive on-farm investment.

Finally, gender effects are strategy-specific, not uniform. Adaptation programs should align practices with gendered roles in rice systems, rather than applying gender-neutral designs. Overall, the evidence supports strategically targeted, scale-sensitive, and institutionally grounded adaptation policies that explicitly reflect the constraints and incentives facing rice farmers in Tanzania.

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