STRATEGIC NON-USE: VILLAGE COOPERATIVES AND LOW-INPUT ADAPTATION TO EXTREME HEAT IN TANZANIA

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Abstract

This paper investigates a counterintuitive climate adaptation strategy: the "strategic non-use" of high-input resources by smallholder farmers in rural Tanzania when faced with extreme heat. We examine the mitigating role of village cooperatives in driving this low-input production behavior and its subsequent impact on maize yields and household welfare. Our study was conducted in three waves from 2008/09 to 2012/13, analyzing the effects of weather shocks on household welfare in Tanzania using data from the Tanzania National Panel Survey and weather data from the Global Land Data Assimilation System (GLDAS) and Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS). We find that extreme heat is a devastating shock, reducing maize yield by 8.9% and household income by 3.0%, with the impact being significantly more severe on households in villages without cooperatives. We uncover a novel dual-mechanism for this institutional resilience: Village cooperatives strategically promote low-input adaptation. We demonstrate that the cooperative's yield-saving mitigation is achieved by rigorously guiding the community to reduce inorganic fertilizer use during the extreme heat season. Simultaneously, cooperatives promote long-term sustainability investments like erosion control. Critically, these contrasting mechanisms reveal a policy trade-off: the short-term benefit of yield protection comes at the cost of the cooperative promoting erosion control, a sustainable measure associated with a significant short-term reduction in farmer income. This finding re-frames the role of cooperatives from being mere input promoters to essential institutions for climate-smart risk management and financing the adoption of sustainable practices. However, these positive effects have a limited impact on small farmers; therefore, establishing more inclusive cooperatives and greater involvement of small farmers in decision-making processes can be effective. Government and policymakers should prioritize village cooperatives in their policy actions, particularly in light of the growing climate risks.

Keywords: Extreme heat; Smallholder farmers; Strategic Non-use; Village cooperatives; Low-input strategy, Sustainability

JEL Codes: *D81; Q12; Q13; Q54; Q56; O13*

1. Introduction

Extreme weather shocks, including extended droughts, excessive floods, and forest fires, impede global economic progress. These shocks are expected to intensify, causing food and water scarcity, internal migration, child malnutrition, and declined crop productivity and income (Burke *et al.,* 2015; Ma & Maystadt, 2017; Block *et al.,* 2018). Therefore, how smallholder households adapt to climate variations matters. This paper investigates a novel and counterintuitive climate adaptation strategy in Tanzania: the "strategic non-use" of high-input resources when faced with extreme heat. We examine the mitigating role of village cooperatives in promoting this low-input production behavior and its subsequent effects on maize yields and household welfare. Like many other countries, Tanzania heavily depends on subsistence agriculture, which puts a significant part of its population at risk of the impacts of climate change (Kimaro *et al.,* 2018; FAO, 2016). About 90% of households rely on crop production and livestock keeping to cater for domestic necessities (Bundala *et al.,* 2020; Mpogole *et al.,* 2020; Patt & Winkler, 2007). Maize is a crucial staple food grown by over 70% of smallholder farmers in the country. Severe heat can disrupt the supply and demand of maize, leading to changes in diet, higher food prices, and reduced income for farmers. This can hinder efforts to combat rural poverty.

We explore the economic implications of extreme heat and the importance of climate adaptation for enhancing food production and increasing the income of rural households. Specifically, our research explores two crucial questions: (1) How does extreme heat affect maize yield and rural household income in Tanzania? and (2) By what precise, empirically verified mechanisms do village cooperatives mediate this impact, and do these mechanisms promote sustainable adaptation? We hypothesize that cooperatives enable a strategic low-input response that challenges the conventional view of high-input adoption as the only pathway to resilience. We tackled these questions using three combined waves of the Tanzania National Panel Survey (TNPS) from 2008/09 to 2012/13 and weather data from 2000 to 2014. Our findings reveal that extreme heat has a detrimental impact on maize yield and household income. Interestingly, households in villages without cooperatives were more impacted by extreme heat than those with village cooperatives. *Importantly*, our mechanism analysis shows that cooperatives support a move toward sustainable, low-input adaptation. This is achieved by encouraging erosion control, crop diversification, and especially a substantial decrease in inorganic fertilizer use during heat shocks. This low-input strategy contradicts the traditional perception of cooperatives as merely promoters of chemical input use and offers a new insight into climate-smart agriculture. The rest of the paper is divided as follows: Section 1.2 covers the literature review. Section 1.3 explores the methods and data used in the study. Section 1.4 delves into the main empirical findings and robustness checks. *Lastly*, section 1.5 concludes the paper and provides policy recommendations.

2. Literature review

Recent empirical studies have concentrated on understanding the climate variability nexus of economic outcomes, aiming to get a more comprehensive picture of the effect of weather shocks on household well-being. These studies use panel and cross-sectional datasets to investigate weather variation and the outcome of interest (Thiede & Strube, 2020; Shumetie & Yismaw, 2018; FAO, 2016; Mertz *et al.,* 2010). They used long-term temperature and rainfall data to analyze the relationship between weather and climate change variables. The literature showed that rising heat waves and erratic rainfalls had an impact on agricultural production, health, labour allocation, migration, and economic growth in developing economies worldwide (Block *et al.,* 2018; Shumetie & Yismaw, 2018; Jessoe *et al.,* 2016; Dell *et al.,* 2014; Mertz *et al.*, 2010; Schlenker & Lobell, 2010). The sector most affected by this is agriculture in terms of crop yield, output, and household income (Letta *et al.,* 2019; Block *et al.,* 2018; FAO, 2016). Ma and Maystadt (2017) reported that temperature and precipitation reduced the maize yields in China. Whereby high-temperature variability reduced maize yields by 1.4% and drought spells by 2.5% in the Northern Spring zone. However, these impacts had limited effects on farmers' total income. Rowhani et al. (2011) showed that a projected increase in temperature by 2°C reduces average rice, maize, and sorghum yields by 7.6%, 13%, and 8.8%, respectively, while a 20% increase in intra-seasonal precipitation variability reduced rice, maize, and sorghum yields by 7.6%, 4.2%, and 7.2%, respectively. The continent of Africa, specifically Sub-Saharan Africa, has garnered significant attention in the literature due to its adverse effects on the agricultural productivity of cereal crops. This is attributed to the considerable share of food calories and nutrients in the African diet and the region's vulnerability to weather-related disturbances. (Blanc, 2012; Roudier *et al.,* 2011; Lobell *et al.,* 2011; Schlenker & Lobell, 2010).

On the other hand, how households cope with weather shocks has also received enormous attention. Coping mechanisms are crucial for households to protect their standard of living and maintain their livelihoods. The scholarly literature has given significant attention to two primary strategies, ex-ante and ex-post climate adaptation. Ex-ante climate adaptation strategies refer to the proactive measures taken before weather shocks. Such measures include employing early planting times, altering crops, diversifying crops, utilizing pesticides and fertilizers, conserving water and soil, and implementing farm management strategies to cope with adverse climate variations (Makate *et al.,* 2023; Ma & Maystadt, 2017; Tesfaye & Seifu, 2016; Tessema *et al.,* 2018). Conversely, ex-post climate adaptation strategies refer to reactive measures after a weather shock. This emphasized livestock buffer, corn stock, and non-farm employment options to attenuate the consequences of weather shock and smoothing farmers' consumption (Aragón *et al.,* 2018; Cui & Tang, 2023). However, most of the smallholder farmers in developing economies reside in rural areas, and the environment is characterized by a scarce credit market, an incomplete insurance market, and information asymmetry (Jensen, 2000; Rosenzweig & Binswanger, 1992), in turn affecting the ability of farmers to cope with weather shocks.

However, studies show that agricultural cooperatives improve crop yields significantly, augment farm efficiency, and enhance financial performance. Similarly, they are pivotal in supporting farmers in adopting agricultural innovations such as improved seeds, pesticides, and inorganic fertilizers (Mojo *et al.,* 2017; Manda et al., 2020; Neupane *et al.,* 2022). Several surveys conducted in sub-Saharan African (SSA) nations, including Kenya, Nigeria, Rwanda, the Democratic Republic of Congo, and Ethiopia, have demonstrated an overwhelmingly affirmative impact of agricultural cooperatives on smallholder farmers' adoption of improved seeds, chemical fertilizers, and pesticides. In Ethiopia, cooperative membership is crucial for smallholder farmers to use inorganic fertilizers. Overall, agricultural cooperatives and other forms of collective action play an indispensable role in promoting rural development and improving the livelihoods of smallholder farmers in developing economies (Wanyama *et al.,* 2008; Shiferaw *et al.*, 2014; Ahmed & Mesfin, 2017; Manda et al., 2020). While the role of cooperatives in technology adoption is established, these studies often focus on promoting high-input adoption. In contrast, we address a critical gap. There is a paucity of empirical evidence on the precise differential mechanisms by which village cooperatives in Tanzania mediate the negative impact of extreme heat (HDD) on smallholder maize farmers, particularly to discern whether these mechanisms involve a strategic reduction in resource use to promote sustainable resilience. Thus, this research addresses an important gap by exploring the mechanisms and trade-offs involved in institutional-led climate adaptation. Our empirical strategy is threefold. *First*, we establish the baseline impact of extreme heat, measured using growing degree days (GDD) and harmful degree days (HDD), on smallholder household outcomes in Tanzania. *Second*, we utilize a net effect framework to decompose the overall cooperative benefit, specifically isolating the channel through which the cooperative influences adaptation strategies (like fertilizer reduction and erosion control) to mitigate the heat shock. *Third,* we analyze how these institutional effects and climate impacts vary between small and medium-scale farmers to evaluate the inclusivity of the cooperative model.

This study makes three significant and timely contributions to the existing literature. It offers detailed, strong evidence on how climate variations affect rainfed agriculture in a major developing economy. More importantly, it redefines the role of agricultural cooperatives from merely promoting high-input technologies to becoming essential institutions for climate-smart risk management, demonstrating that "strategic non-use" constitutes a verifiable and yield-preserving adaptation strategy. *Finally,* by empirically demonstrating the policy trade-off between the immediate costs of sustainable investment (erosion control) and the short-term benefits of shock management, this research provides vital, actionable insights for policy-makers supporting Tanzania's progress toward the Sustainable Development Goals (SDGs 1, 2, and 13) and strengthening rural resilience.

3. Methods

3.1 Empirical strategy

Our empirical analysis focuses on examining how smallholder farmers respond to extreme heat. Hence, we estimate the association between household economic outcomes and cumulative heat exposure, measured in growing degree days. Schlenker and Roberts (2009) assume temperature effects on yield are additively substitutable over time. The nonlinear relationship between plant growth *g(h)* and heat *h* can be expressed by the following generic form:

$$lny_{ijst} = \int_{h}^{\bar{h}} g(h)\varphi_{jst}(h)dh + z_{jst}\delta + \alpha_{ijs} + \delta_{st} + \in_{ijst} \qquad [1]$$

where y_{ijst} is the log household economic outcome in household *i* in district *j* in region *s* in growing season *t*. $\varphi_{it}(h)$ represents the time distribution of the temperature over the growing season. Observed heat ranges between the lower bound *h* and the upper bounds $\bar{h}$. z_{it} denotes the other controls other than temperature. α_{ijs} denotes household fixed effects controlling for time-invariant household traits. δ_{st} connotes the fixed effects for the survey round and region. Finally, $\in_{ijst}$ is the error term. *Furthermore*, we extended the form *g(.)* in Equation 1 by dividing it into two-degree variables, namely: growing degree days (GDD), which is beneficial heat accumulation for favourable crop growth, and harmful degree days (HDD), a heat that hurts crop development. The inclusion of HDD is essential to understand the non-linear impacts of extreme heat. For other weather controls, we included a quadratic of the total precipitation. We defined the GDD and HDD during the maize-growing season as follows:

$$GDD = \frac{1}{n}\sum_{d=2}^{n}(h_d - 8)|(8 \le h_d \le \tau) \qquad [2]$$

$$HDD = \frac{1}{n}\sum_{d=2}^{n}(h_d - \tau_{high})|(h_d > \tau) \qquad [3]$$

Where h_d represents the average daily temperature on day d, and n represents the total number of days during the growing season with valid temperature data. In this case, we focused on the average growing degree days for a straightforward interpretation and efficiently addressing the issue of missing information from satellite errors. For this study, we use the value of τ as the temperature is above $34^{o}C$ (see Figure 1). A similar approach was observed in studies by Cui and Tang (2023) and Ajetomobi (2015) for China and Nigeria, respectively. After incorporating the information above, our regression equation can be written as follows:

$$ln\, Y_{ijst} = \alpha_i + \beta_1 GDD_{jst;h\in(8,34)} + \beta_2 HDD_{jst(34,\infty)} + z_{jst}\delta + \alpha_{ijs} + \delta_{st} + \in_{ijst} \qquad [4]$$

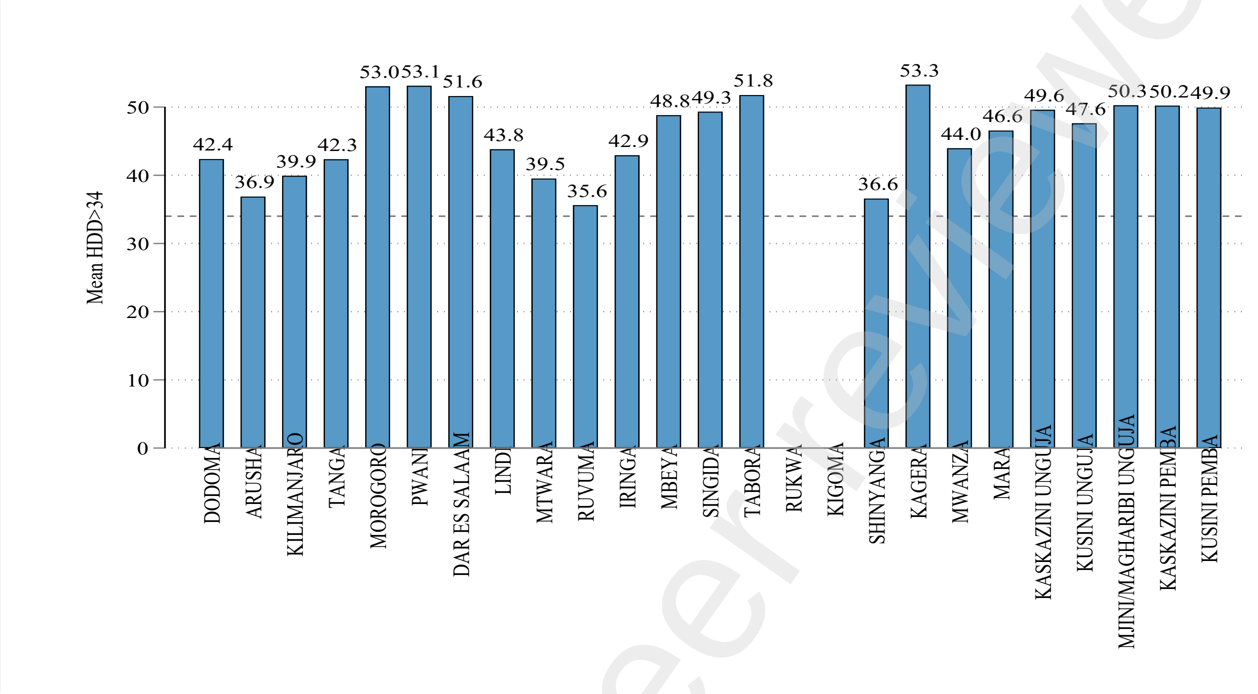

Figure 1: The mean number of growing degree days > 34°C by Region

Source: Author calculations from the data

3.2Data sources

Our study integrated household survey data with satellite imagery to create a comprehensive dataset of agricultural, socioeconomic, and weather variables. The observation unit was a household, and we collected samples from all regions of the country, focusing on maize-growing areas. The final dataset contained approximately 12,000 observations and spanned from 2008 to 2013. Table 1 provides summary statistics.

3.2.1 Farm household data

The three consecutive Tanzania National Panel Surveys (TNPS) were conducted by the World Bank and the Tanzania National Bureau of Statistics between 2008 and 2009, 2010 and 2011, and 2012 and 2013. The Tanzania National Panel Survey (TNPS) was conducted in three waves: the first between October 2008 and September 2009, the second between October 2010 and September 2011, and the third between October 2012 and September 2013. The sample used in this survey represents the entire nation, including mainland rural areas, Dar es Salaam, other mainland urban areas, and Zanzibar. This survey provides estimates of vital socioeconomic variables for each of these areas. They focused on agricultural-producing households that did not move. There were 16,709 individuals from 3265 families in the first wave of the survey. The map reflects national, regional, and significant agroecological zones. A total of 409 enumerated areas across mainland Tanzania and Zanzibar were used to sample families (of which 2063 households were in rural areas and 1202 were in urban areas). A total of 20,559 individuals from 3924 households participated in the second wave of the TNPS. In contrast, approximately 25,412 individuals were enrolled in the third wave from 5015 families. In addition, the TNPS provided information about various household characteristics, including household size, education level, asset holdings, distance to the nearest major road and district capital, and agricultural information about land size, ownership, and crop production. We used this data in different estimation equations. Figure 2 presents the distribution of sampled households across Districts in Tanzania.

3.2.2 Weather data

We used the TNPS Global Positioning System coordinates to link individual and household survey data with daily temperature and precipitation. We preferred to use the daily maximum and minimum temperature data from February 2000 to December 2014, which was extracted from the Global Land Data Assimilation System (GLDAS). The temperature data is in 0.25-degree resolution and was generated using advanced land surface modelling and data assimilation methods (Rodell et al., 2004). Using this data, we calculated the daily minimum and maximum temperatures within 24 hours. We use information on local precipitation to complement the temperature data. To achieve this, I utilize the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) product. CHIRPS merges satellite imagery with monitoring station data to re-analyze a gridded dataset. It provides daily precipitation estimates with a resolution of 0.05 × 0.05 degrees. To connect the household and weather data, we attribute the weather conditions in the cell to a specific household based on its coordinates. We then aggregate the weather data (at daily and monthly frequencies) to obtain the measures of exposure to weather during a particular agricultural year. We focused on the maize-growing season months, ranging from September to January, which is a period in which maize planting and growth occur. We used this period as the definition of the maize-growing season, while the harvest time ranges from November to April, depending on the region. This data was acquired from the Decision Support System for Agrotechnology Transfer (DSSAT).

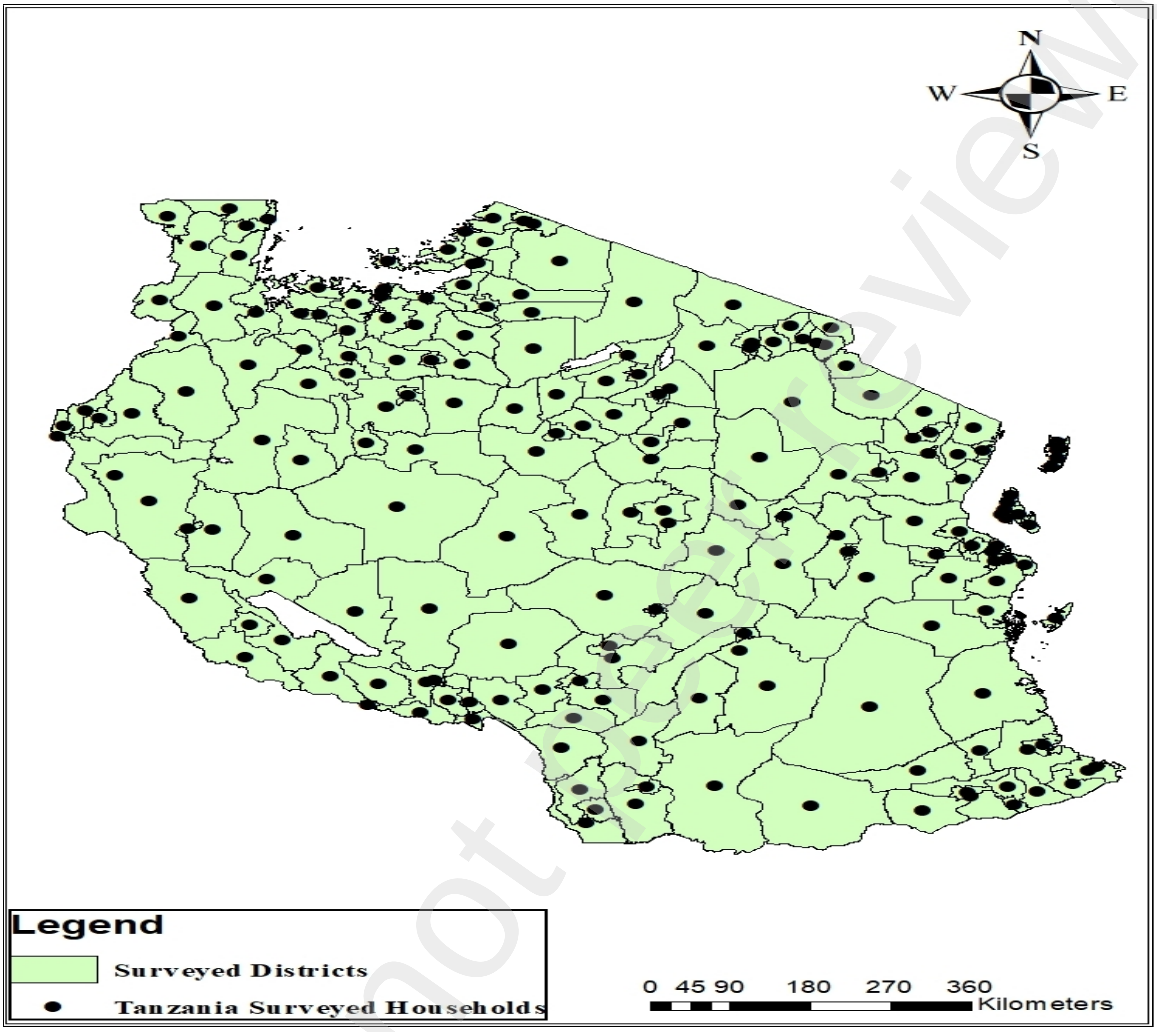

Figure 2: Distribution of Sampled Households across Districts in Tanzania

Source: Author computations from study data

4. Results and Discussions

4.1. Descriptive statistics

Descriptive statistics are provided in Table 1. The average crop revenue is TZS 215870.37/-. Maize, paddy, and beans have an average income of TZS 585,271.03/-, TZS 665,752.36/-, and TZS 311705.3/-, respectively. Maize paddy revenue increased by 248.8% from 2008/09 to 2012/13, maize yield decreased by 35.2%, and maize output was reduced by 25.7% from the same period. The maize-growing season's average temperature and total rainfall are 26 °C and 516 mm, respectively. Across survey years, only 24.8% of the household heads were female, aged around 46 years, with only 60.1% being married. The remaining were either single, divorced, widowed, or separated. The average household size was five members, operating a farm size of 1.3 hectares. The average distance of the household to the nearest market and road is 7.03 km and 0.8 km, respectively. Households in the village with cooperatives increased from 24.8% in NPS 2008/09 to 42.1% in NPS 2012/13 (69.8%), with the majority of these households located in rural areas (77.1%), followed by other urban areas (15.2%) and Dar es Salaam (7.8%). Regarding agricultural inputs in maize growing, on average, farmers used 68.1 kg/ha of inorganic fertilizers and 1.9 kg/ha of pesticides, and 0.4 days/ha were allocated to hired labour. Farm income is computed as total revenue minus the input costs, excluding any cash transfers.

Table 1: Descriptive Statistics

Variables	**Observation**	**Mean**	**Std. Dev.**	**Min**	**Max**
Farm income in TZS					
All crops	5113	215870.37	707664.17	52	30000000
Maize	1036	216629.63	585271.03	1250	8780000
Paddy	514	417616.15	665752.36	3000	5750000
Beans	399	120327.57	311705.3	300	3750000
Crop output in kg					
Maize	1036	887.69	4841.22	1	120000
Paddy	514	1547.63	8488.79	4	120000
Beans	399	176.6	422.34	1	4150
Crop yields in kg/ha					
Maize	1009	1782.88	16527.16	7.41	474442.38
Paddy	493	3230.57	24272.94	14.83	395368.63
Beans	393	333.25	745.55	.49	9884.22
Household-head characteristics					
Gender of the head	12199	.248	.432	0	1
Age of the head	12199	45.643	15.834	16	108
Marital status	12199	.601	.49	0	1
Household size	12199	5.138	3.076	1	55
The education level of the head	11789	5.821	4.126	0	17
Village with cooperatives	9280	0.341	.474	0	1
Land operated by household	9941	1.273	1.84	0	34.398
Durable assets wealth index	12199	.284	.451	0	1
Distance to the nearest market in km	12199	7.032	9.02	0	181
Distance to nearest road in km	12199	.768	2.286	0	90
Agricultural inputs					
Inorganic fertilizer kg/ha	5018	68.086	2001.972	0	98842.164

Pesticides in kg/ha	5018	1.878	34.524	0	1698.85
Hire labour in days/ha	5018	.371	.483	0	1
Weather					
Growing degree days (8-34 °C)	11710	2419.15	418.57	1448.03	6129.43
Harmful degree days (> 34 °C)	11710	.31	.99	0	20.11
Total rainfall in mm	11710	516.775	247.494	121.421	1713.321
Total rainfall squared in mm	11710	1033.55	494.989	242.843	3426.642

Author computation from the study data

4.2. Extreme heat impact on maize yield and household income

We first investigate the impact of degree days on maize yield, then examine the household income. Both the maize yield and household income values were log-transformed. Table 2 presents the results for maize yield. In column (1), we offer the measurements of extreme heat using growing degree days (GDD), harmful degree days (HDD), total rainfall, and total rainfall squared over the maize-growing season using a fixed effects framework. The estimates show that extreme heat harms the maize yield, and the magnitude of the effects is statistically significant. That is, maize yield decreases by 0.9% with each additional degree day above 34^{o}C. The results were statistically significant at a 99% level of confidence. Our estimates in Table 2 remain robust even after adding other specifications such as survey round dummies, household controls, region-fixed effects, and survey round-region effects. Similar studies have found negative impacts of extreme heat on maize yield, such as those by Cui and Tang (2024), Ma and Maystadt (2017), Zhang *et al.* (2015), and Liu *et al.* (2014). On the contrary, an additional degree-day increase in HDD reduces farm income by 0.3% (Table 3). However, when regional dummies and survey round-region dummies were considered, the results were negative but not statistically significant. Reflection from the findings is that temperature fluctuations increase the susceptibility of smallholder farmers to adverse income shocks. Since maize is sensitive to high-temperature variations, higher temperature variations would result in more loss of maize yield and household income (Schlenker & Roberts, 2009; Manahor, 2022).

Table 2: Impact of extreme heat on maize yield: Baseline results

Variables	**Log Maize Yield**			
Growing degree days (8-34 °C)	0.000100	0.000125	0.000208	0.000213
	(0.000123)	(0.000151)	(9.39e-05)	(8.13e-05)
Harmful degree days (> 34 °C)	-0.0893*	-0.0784	-0.0868***	-0.0889**
	(0.0239)	(0.0323)	(0.00776)	(0.00988)
Log of total rainfall in mm	-10.76	-9.913	-0.185	-0.582
	(4.737)	(4.457)	(1.295)	(1.749)
Log of total rainfall squared in mm	0.903	0.833	0.0257	0.0556
	(0.379)	(0.356)	(0.113)	(0.148)
Constant	37.41	34.70	5.295	6.465
	(14.68)	(13.86)	(3.775)	(5.359)
Observations	866	850	850	850
R-squared	0.051	0.061	0.215	0.240
Round dummies	YES	YES	YES	YES
Controls	NO	YES	YES	YES
Region dummies	NO	NO	YES	YES
Round*Region dummies	NO	NO	NO	YES

Note: Robust standard errors are in parentheses. ***, **, and* indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Household controls include gender, age, marital status, family size, education level, agricultural durable assets index, distance to the closest road, and distance to the closest market.

Table 3: Impact of extreme heat on household income: Baseline results

Variables	**Log Household Income**			
Growing degree days (8-34 °C)	0.000237**	0.000189**	0.000105*	0.000102*
	(4.62e-05)	(2.98e-05)	(3.40e-05)	(3.39e-05)
Harmful degree days (> 34 °C)	-0.0668*	-0.0500*	-0.0312	-0.0301
	(0.0177)	(0.0167)	(0.0141)	(0.0130)
Log of total rainfall in mm	0.942	0.402	2.992	2.960
	(1.105)	(0.780)	(1.075)	(1.101)
Log of total rainfall squared in mm	-0.0820	-0.0395	-0.257	-0.256
	(0.0905)	(0.0636)	(0.0947)	(0.0982)
Constant	7.850	9.091*	1.759	2.470
	(3.449)	(2.382)	(3.045)	(2.949)
Observations	3,014	2,969	2,969	2,969
R-squared	0.006	0.058	0.092	0.107
Round dummies	YES	YES	YES	YES
Controls	NO	YES	YES	YES
Region dummies	NO	NO	YES	YES
Round*Region dummies	NO	NO	NO	YES

Note: Robust standard errors are in parentheses. ***, **, and* indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Household controls include gender, age, marital status, family size, education level, agricultural durable assets index, distance to the closest road, and distance to the closest market.

4.3. Differences in extreme heat impact across major maize growing zones

Maize is extensively grown in three zones in Tanzania: the southern highlands, the lake zone, and the northern zone. Among these zones, the southern zone leads in maize production and has a 50% and 25% land allocation, respectively. Regions such as Arusha, Dodoma, Iringa, Mbeya, Rukwa, and Ruvuma are usually maize surplus zones, contributing to 50-60% of the total annual maize production (USDA, 2018; Mdadila, 1995). Due to the significant contribution of these zones to maize production in Tanzania, we decided to examine how extreme heat affects household economic returns (*i.e.,* maize yield, output, land operated per hectare, and maize income). However, all results showed a negative impact across all zones except for maize revenue in the southern zone and land cultivated by hectares in the northern zones. This indicates that without more adaptation measures to tackle climate risks in Tanzania, smallholder households would face significant repercussions across all major maize-growing zones in the country.

Table 4: Impact of extreme heat on household economic returns across zones

Variables	**(1)** **Log Maize Yield**	**(2)** **Log Maize Output**	**(3)** **Log Land operated**
HDD x Southern Highlands	-0.0817	-0.108	-0.0148
	(0.0455)	(0.0630)	(0.0147)
HDD x Northern zone	-0.0732	-0.0968	-0.0308***
	(0.185)	(0.189)	(0.00193)
HDD x Lake zone	-0.0128	-0.0443	-0.0196
	(0.101)	(0.158)	(0.0287)
Observations	866	890	6,249
R-squared	0.230	0.205	0.209
Round FE	YES	YES	YES
Household Controls	YES	YES	YES
Region FE	YES	YES	YES
Round_Region FE	YES	YES	YES

Note: Robust standard errors are in parentheses. ***, **, and* indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Household controls include gender, age, marital status, family size, education level, agricultural durable assets index, distance to the closest road, and distance to the closest market.

We find that extreme heat significantly affects household economic outcomes, making it essential to understand how rural households cope with these adverse weather shocks through climate adaptation strategies. Due to the inherent challenges in developing economies—such as asymmetric information, missing insurance markets, and scarce credit—local social networks are critical. Social networks such as cooperatives are therefore crucial to overcoming these challenges, facilitating climate change adaptation (Lara, 2014; Dave, 2021) and aiding communities in transitioning towards sustainable and resilient practices and local climate governance (Schoder & Walk, 2013). However, the feasibility of adaptation differs across contexts and agroecosystems (Shapiro-Garza et al., 2020). To test the mitigating effect and mechanisms of these institutions, we extended our model in Equation 4 by focusing on the interaction between extreme heat and village cooperatives, as shown in the fixed effects model below:

$$ln\, Y_{ijst} = \alpha_i + \beta_1(HDD_{jst(34,\infty)} * D_{jst}) + z_{jst}\delta + \alpha_{ijs} + \delta_{st} + \in_{ijst} \qquad [5]$$

where y_{ijst} is the log household economic outcome in household *i* in district *j* in region *s* in growing season *t*. $(HDD_{jst(34,\infty)} * D_{jst})$ is the interactive term between extreme heat and village cooperatives *(i.e.,* a dummy variable whereby 1 if a household lives in a village with cooperatives and 0 if it is otherwise). z_{it} denotes the other controls other than temperature. α_{ijs} denotes household fixed effects controlling for time-invariant household traits. δ_{st} connotes the fixed effects for the survey round and region, while $\in_{ijst}$ is the error term.

A key methodological challenge is that $\text{HDD} \times \text{Cooperative}$ studies often suffer from endogeneity. By focusing on village cooperative presence and using the Household Fixed Effects (FE) model, we mainly address two primary sources of bias. *First*,α_{ijs}controls for household-level, time-invariant factors like unobserved farmer ability and risk preferences, which influence selection into membership. *Second*, it accounts for unobserved, time-invariant village characteristics such as baseline agro-ecological conditions and fixed geographic advantages. Given that the study focuses on the heterogeneous impact of an exogenous shock (extreme heat, HDD), the FE framework is the most appropriate quasi-experimental method for identifying the varied impacts of cooperative presence on changes in adaptation strategies.

4.4. Total Impact of Village Cooperatives (Baseline)

Results in Table 5 show that the households in villages without cooperatives were significantly affected by extreme heat compared to villages with cooperatives. This could be associated with cooperatives providing farmers access to shared resources, such as irrigation facilities, improved seeds, and agricultural inputs, essential for mitigating extreme heat's effects on crop production. Farmers who reside in villages that do not have cooperatives may encounter numerous challenges in accessing essential resources individually. These challenges can reduce the ability to cope with heat stress and maintain agricultural productivity during challenging climatic conditions. In contrast, farmers who live in villages with cooperatives often benefit from collective risk-sharing mechanisms and coordinated responses to extreme weather events. Cooperative members can pool resources, share knowledge, and implement joint adaptation strategies that enhance their resilience to heat stress. Conversely, farmers who reside in villages without cooperatives may lack the support systems and collaborative structures necessary to effectively manage the risks associated with extreme heat, rendering them more vulnerable to its detrimental impacts on their agricultural livelihood.

Table 5: Total effect of village cooperatives during extreme heat *(Baseline results)*

Variable	**Log of Maize yield**	**Log of Crop yield**	**Log of Household Income**
HDD x No village coops	-0.126*	-0.0245***	-0.0629*
	(0.0658)	(0.00113)	(0.0381)
HDD x Village coops	-0.0643	-0.0129	-0.0230
	(0.0467)	(0.0275)	(0.0319)
Constant	4.867	2.001	4.984
	(8.781)	(4.444)	(4.778)
Observations	749	3,779	2,688
Round FE	YES	YES	YES
Household Controls	YES	YES	YES
Region FE	YES	YES	YES
Round_Region FE	YES	YES	YES

Note: Robust standard errors are in parentheses. ***, **, and* indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Household controls include gender, age, marital status, family size, education level, agricultural durable assets index, distance to the closest road, and distance to the closest market.

1.4.1 Modelling for cooperative influence on adaptation strategies

To model the channels driving the cooperative's mitigating effect, we incorporate the interaction term for village cooperatives and extreme heat ($\text{HDD} \times \text{Co - op}$) on farmers' adoption of ex-ante adaptation strategies. Given the mixed nature of the dependent variables, where erosion controls and crop diversification are dummy variables, and inorganic fertilizers, pesticides, and land use are continuous variables (log-linearized), we utilized `xtlogit` for the binary outcomes and `xtreg` for the continuous outcomes. The general form of the adaptation model is expressed as follows:

$$CS_{ijst} = \alpha_i + \beta_1(HDD_{jst(34,\infty)} * D_{jst}) + z_{jst}\delta + \alpha_{ijs} + \delta_{st} + \in_{ijst} \quad [6]$$

where CS_{ijst} is a binary or log of climate adaptation strategies (*i.e.,* erosion controls, crop diversification, inorganic fertilizer, pesticides, and land use) by household i in district j in region s in growing season t. $(HDD_{jst(34,\infty)} * D_{jst})$ is the interactive term between extreme heat and village cooperatives *(i.e.,* a dummy variable whereby 1 if a household lives in a village with cooperatives and 0 if it is otherwise). z_{it} denotes the other controls other than temperature. α_{ijs} denotes household fixed effects controlling for time-invariant household traits. δ_{st} connotes the fixed effects for the survey round and region, while $\in_{ijst}$ is the error term.

4.5. Cooperative influence on erosion controls and crop diversification

Our results in Table 6 show that households in villages with cooperatives significantly used erosion control measures during extreme heat compared to households in villages without cooperatives. This positive can be associated with knowledge sharing, capacity building, and education platforms such as seminars and workshops, which promote their adaptation efforts. Similarly, the effect is positive but insignificant for crop diversification; however, the heat shock significantly reduced crop diversification for the village without cooperatives. This can be associated with a lack of village cooperatives, which may affect farmers' access to agricultural extension services, technical support, and market information that could enable them to diversify their crops to mitigate the impact of extreme heat. In addition, a shortage of resources and knowledge-sharing platforms hinders farmers' decision-making on crop selection and management practices. This may, in turn, make farmers in villages without cooperatives more risk-averse, and conservatives prioritize growing only crops perceived as more familiar to them. Cooperatives are known to function as social centers that promote networking, collaboration, and mutual support among farmers. When farmers are part of a cooperative, they can benefit from social capital and community ties that can help facilitate collective action, knowledge sharing, and joint decision-making on erosion control measures. This aligns with findings by Derso *et al.* (2022) that cooperatives improve farmers' crop diversification in rural Ethiopia.

Table 6: Interaction between erosion controls and crop diversification

Variables	**Erosion controls**	**Crop diversification**
HDD x No village coops	0.0187	-0.112*
	(0.0395)	(0.0624)
HDD x Village coops	0.0879***	0.00392
	(0.0238)	(0.0314)
Constant	4.812	13.32***
	(8.570)	(3.277)
Observations	4,575	3,624
Round FE	YES	YES
Household Controls	YES	YES
Region FE	YES	YES
Round_Region FE	YES	YES

Note: Standard errors (in parentheses) are clustered at the region level. Stars indicate statistical significance: *** *p<0.01,* ** *p<0.05,* * *p<0.1*. Household controls include the gender of the head, age of the head, marital status, household size, education level of the head, agricultural durable assets index, distance to the nearest road, and distance to the nearest market.

4.6. Cooperative influence on agricultural inputs

Results in Table 7 show the two primary shifts in input behaviour in the village with cooperative: a non-significant increase in pesticide use, which may indicate a collective response to heat-related pest proliferation. A significant reduction in inorganic fertilizer use. These findings suggest that the cooperative's overall benefit is not from universal input promotion, but from a strategic shift in resource management during a shock. In the next section, we test the hypothesis that the observed reduction in fertilizer use constitutes the primary channel through which the cooperative safeguards household yield and income**.**

Table 7: Cooperative influence on input use during extreme heat

Variables	**Log of Pesticides**	**Log of fertilizers**	**Log of land use**

HDD x No village coops		0.0758		0.0214		-0.0302
		(0.0389)		(0.129)		(0.0179)
HDD x Village coops	0.665		-0.166*		0.0163	
	(1.677)		(0.0562)		(0.0130)	
Constant	-24.07	-23.95	-9.730	-8.685	-9.708**	-8.754**
	(28.35)	(29.72)	(20.92)	(17.97)	(1.252)	(1.466)
Observations	405	405	559	559	5,496	5,496
R-squared	0.200	0.200	0.240	0.239	0.348	0.348
Round FE	YES	YES	YES	YES	YES	YES
Household Controls	YES	YES	YES	YES	YES	YES
Region FE	YES	YES	YES	YES	YES	YES
Round_Region FE	YES	YES	YES	YES	YES	YES

Note: Robust standard errors are in parentheses. ***, **, and* indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Household controls include gender, age, marital status, family size, education level, agricultural durable assets index, distance to the closest road, and distance to the closest market.

4.7. Decomposing the Cooperative Benefit: Net Effect and Dual Mechanisms

We extend our analysis to identify the precise channels through which village cooperatives mitigate the adverse effects of extreme heat. By employing the single-channel net effect regression framework (Table 7A), we decompose the total effect observed in Table 5 into components explained by specific adaptation variables. This process verifies two distinct mechanisms driving cooperative resilience: acute shock management and long-term sustainability investment.

Mechanism 1: Strategic Low-Input Adaptation

Results in Table 7A, Panel A, the level of inorganic fertilizer is included as a control, the coefficient on HDD x Village coops interaction term for log maize yield shifts from a small benefit (Total effect ≈−0.064) to a significant loss (Net effect ≈−0.501, *p<0.005*). This substantial magnitude shift proves that the cooperative's total yield-saving effect is achieved by reducing the use of inorganic fertilizers during the heat shock. The cooperative acts as a crucial knowledge-diffusing institution, guiding the community to strategically avoid this high-input practice, which is further justified by the finding that log of inorganic fertilizer has a significant positive impact on farm income (Coefficient=0.306, *p<0.1*), indicating that the cooperative is guiding farmers to trade potential income gain for necessary risk avoidance in the face of acute climate shock.

Mechanism 2: Costly Investment in Long-Term Sustainability

On the other hand, our analysis of erosion control pinpoints a key policy-trade-off (Table 7A, Panel B). After controlling for the adoption of erosion control measures, the co-operative's yield mitigation does not substantially change ($\text{Net effect} \approx -0.052$). This indicates that erosion control is not the primary mechanism for protecting short-term yield. More importantly, the erosion control variable itself exhibits a significant negative correlation with household income. ($\text{Coefficient} = -0.161, p < 0.05$). This strongly indicates that although cooperatives facilitate sustainable and long-term investments such as erosion control, these initiatives entail immediate financial or labor costs for rural households within the short-term observational period. Therefore, the village cooperative's role is twofold: first, in offering an immediate shock-absorbing mechanism (reduced fertilizer use), and second, in making a costly investment toward long-term environmental sustainability.

Table 7A: Impact of Extreme Heat and Cooperatives on Outcomes (Net Effect of Adaptation Mechanisms)

Variables	**(1)** **Log Maize Yield**	**(2)** **Log Farm Income**	**(3)** **Log Maize Yield**	**(4)** **Log Farm Income**
Panel A: Controlling for inorganic fertilizer				
HDD x No village coops	-0.226	-0.0675		
	(0.127)	(0.164)		
HDD x Village coops	-0.501**	-0.302**		
	(0.0585)	(0.0556)		
Log of inorganic fertilizer	0.335	0.306*		
	(0.289)	(0.0746)		
Panel B: Controlling for Erosion Control				
HDD x No village coops			-0.107	-0.0392
			(0.0534)	(0.0320)
HDD x Village coops			-0.0523	0.00580
			(0.0512)	(0.0312)
Erosion control (1/0)			0.116	-0.161**
			(0.216)	(0.0212)
Observations	153	477	671	2,438
R-squared	0.270	0.196	0.261	0.111
Number of rounds	3	3	3	3

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Household controls include the gender of the head, age of the head, marital status, household size, education level of the head, agricultural durable assets index, distance to the nearest road, and distance to the nearest market.

4.8. Inclusivity Challenge: Differential Adaptation by Farm Size

Despite our previous results showing that households belonging to villages with cooperatives cultivate more land than those without cooperatives. We decided to explore further since previous studies have shown that cooperatives benefit medium-scale farmers more than small-scale farmers because they can afford membership risks and costs (Bijman & Wijers, 2019). Farmers are categorized into two sizes: small (<3 hectares) and medium-scale (>3 hectares). Research shows that medium-scale farmers have a greater impact than small-scale farmers. This is because medium-scale farmers have more benefits, such as access to inputs at lower costs, access to markets, economies of scale in marketing, and access to extension services. Unfortunately, these benefits are often not available to small-scale farmers.

Table 8: Differential Adaptation by Farm Size

Variables	**Small-farmers**		**Medium-size farmers**	
HDD x Village coops		-0.0109		0.0127**
		(0.00539)		(0.00245)
Constant	-7.522**	-8.099**	0.493	0.340
	(1.194)	(0.979)	(1.603)	(1.536)
Observations	4,681	4,681	1,587	1,587
R-squared	0.255	0.254	0.204	0.205
Round FE	YES	YES	YES	YES
Household Controls	YES	YES	YES	YES
Region FE	YES	YES	YES	YES
Round_Region FE	YES	YES	YES	YES

Note: Robust standard errors are in parentheses. ***, **, and* indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Household controls include gender, age, marital status, family size, education level, agricultural durable assets index, distance to the closest road, and distance to the closest market.

4.9. Discussions of Findings

The study investigated how extreme heat impacts small-scale maize farmers and how village cooperation influences adaptive strategies to build resilience. The following discussion synthesizes the key insights obtained from our analysis:

First, we find evidence that extreme heat shock reduced rural Tanzania's maize yield and farm income. This can be associated with exposure to high temperatures, which deters maize reproduction in pollen viability, fertilization, and grain development, reducing the maize yield by an average of 85% (Hatfield & Prueger, 2015). In addition, the intensity of heat waves reduces soil moisture, which can affect the plant water flux and, in turn, may reduce the maize yield and revenue (Cramer et al., 2009). Our findings also corroborate previous studies that found exposure to weather shocks reduces maize yield and income (Asseng et al., 2014; Block et al., 2018; Shao et al., 2021; Qin et al., 2023; Cui & Tang, 2023; Simanjuntak et al., 2023). *Importantly*, households in villages with cooperatives experience a much less severe initial impact, showing that the institutional framework serves as an effective, albeit complex, buffer against climate risk.

Second, we identified the two distinct mechanisms driving the cooperative's resilience, as verified by our Net Effect decomposition (Table 7A). *First*, the cooperative acts as an acute-shock yield buffer via strategic low-input adaptation. This is shown by shifting (Net effect coefficients for yield from $\text{Total} \approx -0.064$ to $\text{Net} = -0.501$ for yield) when controlling for inorganic fertilizer. This conclusively demonstrates that the cooperative's immediate benefit comes from strategically reducing inorganic fertilizer use during heat stress. This evidence shifts the cooperative's role from simply promoting high inputs to being a key player in climate-smart non-use for risk management. On the other hand, the cooperative promotes long-term sustainability that involves an immediate cost. While cooperatives influence the adoption of erosion control measures, the Net effect analysis indicates that this does not account for the short-term yield benefit. More importantly, the erosion control variable is associated with a significant short-term reduction in farm income. This finding confirms that the cooperative plays a dual role: it supports a vital long-term sustainability investment, which currently adds a financial or labor burden on smallholders, and also provides immediate shock mitigation. This combination, addressing short-term needs while encouraging costly long-term investments, forms the basis of community resilience.

Third, beyond the adaptation mechanism, we find that the benefits of cooperation are not equally distributed based on farm size. Our analysis of land use shows that medium-scale farmers increased cultivated land during the extreme heat season compared to small-scale farmers (Table 8). This heterogeneity indicates that larger farmers, who face fewer resource limitations, are more likely to fully benefit from collective action's advantages, such as economies of scale, bulk input procurement, and extension services. Therefore, although cooperatives play a crucial role in adaptation, they need to tackle the ongoing challenge of inclusivity to ensure that the benefits of their dual approach reach the most vulnerable smallholder farmers.

4.10. Robustness check

A robustness check was undertaken to ensure my coefficients of the main variables are not insensitive to adding or dropping variables, and this was done for four main variables in our study, which are logarithms of (maize yield, maize output, maize revenue, and land used). In Table 9-Panel A, a month of interview and zone fixed effects, which mainly removes any bias in the agricultural season, is far in the past (household controls were included). Moreover, we clustered our standard errors at the zone level to allow the shock to correlate within the zone, and still, our estimates did not improve substantially. In Rows 3-4, we examined the temperature at thresholds 29 °C and 34 °C, and our results were still strong on maize yield and output. Even with the inclusion of climatic regions, our estimates hold despite only being significant for maize yield in the Southern Highlands. Our results are more consistent with maize yield, but less so with maize revenue and land use.

Table 9: Robust check on household economic outcomes

Variable	**Log (Maize Yield)**	**Log (Maize Output)**	**Log (Land used)**
Panel A: Fixed effects and uncertainty			
1. Month of interview and zone FE	-0.0180	-0.0152*	0.00658**
	(0.00703)	(0.00401)	(0.000902)
2. Clustering in the zone	-0.0201*	-0.0158***	0.00581*
	(0.00500)	(0.000850)	(0.00137)
Panel B: Temperature changes			
3. HDD>29^{o}C	-0.0183*	-0.0101**	-0.00100
	(0.00490)	(0.00119)	(0.000940)
4. HDD>34^{oC}	-0.0879**	-0.109*	-0.0144
	(0.00978)	(0.0327)	(0.0159)
Panel C: Climatic zone			
5. Southern Highland; HDD>29 ^{o}C	-0.0162*	-0.0162	-0.000232
	(0.00471)	(0.0124)	(0.00299)
6. Northern: HDD>29^{o}C	-0.0357	-0.0235	0.00265
	(0.0379)	(0.0255)	(0.00193)

Note: Robust standard errors are in parentheses. ***, **, and* indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Household controls include gender, age, marital status, family size, education level, agricultural durable assets index, distance to the closest road, and distance to the closest market.

5. Conclusions and Policy Implications

This study investigates a counterintuitive climate adaptation strategy: the "strategic non-use" of high-input resources by smallholder farmers in rural Tanzania when faced with extreme heat. We examine the mitigating role of village cooperatives in driving this low-input production behavior and its subsequent impact on maize yields and household welfare. Using panel-data techniques, we analyzed data from the Tanzania National Panel Survey and daily weather data from the Global Land Data Assimilation System (GLDAS) and Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS). Our findings suggest that increased extreme heat negatively affects smallholder maize households in rural Tanzania. This reduces maize yield and farm income by 8.9% and 3.0%, respectively. Furthermore, our results indicate that households in villages with cooperatives have significantly higher maize yield, crop yield, and household income than those without cooperatives.

Furthermore, our net effect analysis shows that a dual approach to climate-smart resilience enhances mitigation efforts. Cooperatives help protect yields by strategically reducing inorganic fertilizer use during heat shocks, transforming from mere input suppliers to risk managers. At the same time, their advocacy for erosion control, a vital long-term sustainability measure, leads to a notable short-term decrease in household income. This clearly confirms the pivotal role of cooperatives in helping farmers navigate the difficult policy choice between immediate financial health and long-term environmental sustainability. In addition, co-operatives are less effective for the smallest farmers, highlighting a failure in benefit distribution.

Therefore, we provide three policy recommendations: *first,* given the importance of erosion control as a long-term sustainability measure with a negative impact on income, the government should subsidize the adoption costs through cooperatives by offering conditional cash transfers for soil and water conservation (SWC) activities to offset the immediate burden on smallholders. *Second,* Agricultural extension and cooperative programs should reduce generalized input promotion by focusing on weather-indexed advisory services that clearly direct farmers on when and how much to cut back high-input resources, such as inorganic fertilizer, during extreme heat periods. Finally, Government and development partners should provide targeted capital and training to co-operatives, establishing mechanisms like progressive fee structures and micro-finance windows to ensure vulnerable smallholders have equitable access to inputs, risk information, and decision-making roles.

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