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Effects of Climate Change Adaptation Strategies on Maize Productivity among Smallholder Farmers in Dodoma, Tanzania

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Abstract: This study sought to establish the impact of climate change adaptation strategies on maize productivity among smallholder farmers in Dodoma, Tanzania. Employing a cross-sectional research design, data was collected from 274 respondents who were randomly selected. A structured questionnaire was utilized for data collection, and the Propensity Score Matching (PSM) technique was employed to estimate the effects of climate adaptation strategies on maize productivity. The findings indicate that smallholder farmers who adopted climate change adaptation tactics achieved higher maize yields compared to non-adopters. Additionally, results from multiple linear regression demonstrate that increased maize yields are associated with the adoption of drought-resistant maize varieties, intercropping, minimal tillage, adjusted planting dates, fertilizers, irrigation and short-duration maize varieties. Notably, crop rotation showed no significant effect on maize productivity. Policy recommendations include government investment in promoting the adoption of climate change adaptation strategies among smallholder farmers to mitigate losses and improve the farmers' well-being. Furthermore, investments in modern irrigation schemes and the use of drought-resilient seeds are deemed crucial for enhancing agricultural resilience in the face of climate change.

Keywords: Smallholder Farmers; maize Productivity; climate change; climate change adaptation strategies.

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Introduction

The agricultural sector plays a significant role in the global economy in terms of employment generation, food security and accumulation of income, among other benefits (FAO, 2021). Globally, the sector creates more jobs than any other except the service sector, with Sub-Saharan Africa, accounting for the most employment shares in agriculture at a rate of 48.4% with the least shares coming from Europe which contributes only 5.1% of the total population that is employed (OECD, 2019; Kitole, 2023; Kitole and Sesabo, 2022). Additionally, the sector is essential to achieving sustainable development as it is crucial in the achievement of several sustainable development goals such as the elimination of poverty, hunger and gender inequality as well as the stimulation of economic growth and decent work, and the fight against climate change and its effects (Kitole & Sesabo, 2024; FAO, 2021).

Given the importance of the agricultural sector in the global economy, climate change poses a serious threat to the performance and overall development of the sector (Kitole et al. 2023b; FAO, 2022; Unganai & Murwira, 2010). For many years now, climate change has negatively affected the performance of the agricultural sector in many economies by reducing productivity rates of different crops like maize, wheat and rice such that it increases the rates of poverty, hunger and food insecurity due to low amount of crop yields, among other critical impacts (Adeagbo et al., 2021; Adhikari et al., 2015; FAO, 2022; Ngetich et al., 2022; Kitole et al. 2023c). However, the consequences of climate change on the agriculture sector vary greatly among economies with developing countries being the most vulnerable than developed countries due to their heavy reliance on climate variables like rainfall for production purposes (Diallo et al.,2020; Donkor et al., 2020; Makuvaro et al., 2018), especially those in Sub-Sahara Africa.

Tanzania is similar to other Sub-Saharan African countries in that it depends on agriculture for economic growth and development (FAO, 2022; Mbilinyi et al., 2013). However, the countries' heavy reliance on rain fed agriculture acts as a serious danger to the people's livelihoods, especially those who mostly depend on agriculture for a living mainly due to climate changes that tend to affect production and productivity rate of several crops such as maize which is regarded as one among the major crops that are produced and traded globally (Kitole et al. 2023d; FAO, 2022). For instance, in 2020, it was estimated that almost 39% of maize produced was sold in the global market, placing it second only to wheat which was sold by 40%. In Tanzania, maize was the most produced crop in 2020, with over 6,711,000 tons being produced (Kitole et al. 2024a; Dimoso and Andrew, 2021). This indicates that maize is one of the major and most important crops in Tanzania and the global market. However, studies indicate that the productivity rate of maize is anticipated to decrease, especially in Sub-Saharan Africa, due to temperature increases and a decrease in the level of precipitation (Kitole et al. 2024b; Soglo & Nonvide, 2019).

Adapting to climate change in the agricultural sector is key to improving the productivity of both crops and livestock (Marie et al. 2020; Mbilinyi et al., 2013). Countries and international organizations through various ways such as the establishment of global agreements have proposed several adaptation options to cope with climate change impacts on the agricultural sector (Akinyi et al., 2021; Kitole et al. 2024c). Hence, the proposed adaptation measures by countries and international organizations have gone in hand with other several adaptation practices that are being employed and implemented by individuals and other stakeholders at their own choices(Kihupi et al., 2015; Fumbwe et al. 2021).

This study sought to establish the effects of climate change adaptation techniques on the productivity of maize, particularly for the smallholder farmers since they are regarded as the most vulnerable group in terms of the impacts brought by climate change on the agricultural sector that keeps on affecting their agricultural and livelihood activities mainly due to their low adaptive capacity especially those located in Sub-Sahara Africa (Atube et al., 2021; Kitole and Utouh, 2023). Moreover, smallholder farmers' adaptation to climate change will be crucial in reducing poverty rates and ensuring food security.

It is estimated that each Tanzanian consumes 112.5 kilos of maize annually amounting to a national consumption of over 3 million tons (Temu et al., 2011; Kitole et al., 2023a). Smallholder farmers contribute to approximately 85% of the nation's total maize output, playing a significant role in the production of the crop. The findings in this study are therefore essential for successful adaptation planning at the local level for improved maize productivity.

Literature Review

This section encompasses both theoretical and empirical literature reviews. In the theoretical review, the study explicitly delves into the theory of production, providing a comprehensive understanding of its key concepts and principles. In the empirical review, a multitude of studies on similar topics are explored, offering valuable insights and perspectives from existing research in the field.

Theoretical Literature Review

The theory of production was adopted for this study. The theory was established by neoclassical economists, the focus being on the objectives of the firm which are; cost minimization, output maximization and profit maximization (Thomas & Maurice, 2016). Based on this idea, this study is limited to the output maximization objective since smallholder farmers adopt climate change adaptation strategies to reduce the impacts brought specifically by climate change and help improve maize productivity.

The theory is comprised of a production function that portrays the physical relationship between a given set of inputs and outputs. In this study, maize yield is considered as an output and a given set of inputs along with the measures of coping with climate change adaptation strategies is a set of technologies that smallholder farmers adopt to improve maize yields. The production function is expressed as follows:

$$Q = f\ (\alpha i\ , \beta i)$$

Where; Q represents maize yield produced by smallholder farmers, αi is a given set of inputs and βi is a given set of climate change adaptation strategies. The production function can further be expressed mathematically as follows:

$$MaizeYield(Y) = a + bx_i + cy_i$$

Where, a, b, and c represent the parameters that will be estimated, x_i represent a set of inputs, and y_i represent the adopted climate change adaptation strategies.

Empirical Literature Review

Previous studies on the effects of climate change adaptation strategies at the farm level focused on the productivity of crops in general, with a few studies focusing on maize productivity. In a comparative study that included 1000 farm households in Ethiopia, Di-Falco et al. (2011) determined the contributions of climate change adaptation strategies on enhanced crop yields. The study concluded that adopting climate change adaptation measures increased the agricultural productivity. These results are comparable to those of Khanal et al. (2018) who conducted a comparative analysis to look at the effects of climate change adaptation strategies on food productivity in Nepal. The study found that the adoption of climate change adaptation measures had a beneficial influence on food productivity, with adopters producing 20% more than non-adopters and 12% more if they had not. The studies by Di-Falco et al. (2011) and Khanal et al. (2018) both provide insightful data on the effects of climate change adaptation measures; however, they are not specifically focused on maize productivity.

Kuntashula et al. (2014) examined the effects of climate change adaptation strategies on maize productivity in Zambia using the cross-sectional research design with 1231 randomly selected households. The study discovered that crop rotation and minimal tillage increased the maize productivity by 21-24 percent and 26-38 percent, respectively. Moreover, the study had several limitations including its application because it opted to focus primarily on crop rotation and minimal tillage as adaptation strategies. It may have been more relevant if they had widened the scope of their research and concentrated on a variety of adaptation strategies. Moreover, Diallo et al. (2020) employed multi-stage and simple random sampling approaches to collect 308 smallholder farmers for structured questionnaire interviews. The findings show that more than half of the respondents used organic fertilizers and early maturity types. They also shifted their planting dates as adaptation techniques. Among the three techniques, only modifying the planting date was shown to not affect maize productivity.

Methodology

This study employed the cross-sectional research design which allowed the collection of data at a single point in time to establish the relationship between variables of interest.

Population and Sampling

The population of interest comprised maize farmers in the Dodoma Region, totaling 874 individuals. Random sampling techniques were utilized to select a representative sample of 274 smallholder farmers from the population. The sampling ensured that each member of the population had an equal chance of being included in the study, enhancing the generalizability of the findings to the larger population.

Instruments

Data collection instruments consisted of a structured questionnaire administered to the sampled smallholder farmers. The structured questionnaire was designed to gather quantitative data on various aspects, including crop yield, climate change adaptation strategies, agricultural inputs used, and socioeconomic characteristics of the farmers. The questionnaire format facilitated systematic data collection and enabled efficient analysis of responses.

Validity and Reliability

Validity and reliability were ensured through rigorous pre-testing and piloting of the questionnaire prior to the main data collection phase. This involved assessing the clarity, comprehensiveness and relevance of the questionnaire items, as well as conducting reliability tests to ensure consistency in responses.

Statistical Treatment of Data

Statistical treatment of data involved descriptive and inferential analysis. It included regression analysis to establish the relationships between variables of interest.

Ethical Considerations

Ethical considerations were paramount throughout the research process. For instance, the researcher obtained the informed consent from participants and ensured confidentiality.

Model Specification

In determining the effect of climate change adaptation strategies on maize productivity, the authors compared the outcomes between those who adopted (treatment) and those who did not (control group). However, due to differences in various background characteristics between the two groups such as socio-economic characteristics among others, the results were expected to be biased. To address the selection bias problem, the adoption of the propensity matching approach was necessary to provide a better-matched comparison outcome and unbiased results by creating a new control group that is better matched with the treatment group (Kane et al., 2019).

Initially, the researchers began by estimating the propensity scores which is the conditional likelihood of adopting any of the listed climate change adaptation strategies by considering the pre-adoption features of the smallholder farmers as follows:

$$P(W_i)(\Pr(K_i = 1|W_i) = E(K_i|W_i)P(W_i) = b\{f(W_i)\}$$

Where: K_i is an indicator of adopting the climate change adaptation strategies, W_i represents the vector of the characteristics before adopting the climate change adaptation strategies, b (.) can represent either a normal or logistic cumulative distribution. The adopted matching methods in this study are the nearest neighbor, radius and kernel matching techniques where the probit model was used to estimate the propensity scores. The parameter of interest in propensity score matching is the average treatment effect which portrays the impact of adopting and not adopting the climate change adaptation strategies on maize productivity. The average treatment effect on the treated is expressed as:

$$ATT = E\left[E\left(Z_i^1\middle|K_i = 1P(W_i)\right)\right] = E\left[E\left(Z_i^0\middle|K_i = 1P(W_i)\right)\middle|K_i = 1\right]$$

Where: Z_i^1 and Z_i^0 are the counterfactual results for adopting and not adopting the climate change adaptation strategies among the maize smallholder farmers.

Furthermore, a set of conditions were considered in performing the propensity score matching approach. This includes the Roy-Rubin model which is the basic framework in the performance of this study (Roy, 1951; Rubin, 1974). Individuals (smallholder farmers), treatment (adoption) and outcomes are the main elements of this model. If an individual (smallholder farmer) i receives treatment (adopts the climate change adaptation strategies), the treatment indicator DV_i = 1; otherwise, it will be equal to zero. The possible outcomes are then specified as $DV_i Z_i$ for each individual (smallholder farmer) i where $i = 1$. The treatment effect for a smallholder farmer (an individual) is calculated as follows:

$$T_i = Z_i(1) - Z_i(0)$$

Where, $Z_i(1)$ represents the value of the outcome i when the smallholder farmer adopts the climate change adaptation strategy (treated), and $Z_i(0)$ represents the value when the smallholder farmer is not adopting (not treated).

Another crucial aspect to consider is the parameter of interest, specifically the average treatment effect (ATT). This parameter illustrates the impact of adopting or not adopting climate change adaptation strategies on maize productivity, encompassing the entire population. The average treatment effect is calculated as follows:

$$ATT = E\left[E\left(Z_i^1\middle|K_i = 1P(W_i)\right)\right] = E\left[E\left(Z_i^0\middle|K_i = 1P(W_i)\right)\middle|K_i = 1\right]$$

Where: Z_i^1 and Z_i^0 are the counterfactual results for adopting and not adopting the climate change adaptation strategies among the maize smallholder farmers.

Additionally, the Conditional Independence Assumption which is the alternative method of identification is to presume, given a set of observable variables X that are unaffected by treatment (adoption), that the probable outcomes are unaffected by treatment (adoption) assignment.

$$Z(0), Z(1) \text{ II } \frac{DV}{X}, ZX$$

The above condition shows that selection is mainly based on the qualities of the observables and that we may be able to observe all the variables that influence the treatment assignment and potential consequences at the same time. This condition must be supported by the availability of quality data. Rosenbaum and Rubin (1983) proposed the use of balancing scores to cope with this dimensionality problem. They established that if possible, outcomes are unaffected by treatment conditional on variables Z, they are similarly unaffected by therapy conditional on a balancing score $b.(Z)$. One such balancing score is the propensity score $P\ (DV\ \frac{1}{X}\ =\ P(X)$, which is the probability of an individual to engage in treatment (to adopt the climate change adaptation strategies) given his observable variables X.

Moreover, the common support condition which eliminates the anomaly of the $DV's$ complete predictability given X: This condition considers that smallholder farmers with the X values have an equal chance of either being referred as adopters or non-adopters of the climate change adaptation strategies.

$$(Overlap)\ 0\ <\ P\ (DV\ =\ \frac{1}{X})\ <\ 1$$

Moreover, when considering the Conditional Independence Assumption and assuming that there is overlap between both groups, namely adopters and non-adopters of climate change adaptation strategies, the Propensity Score Matching (PSM) estimator emerges as a key tool. This estimator calculates the mean difference in outcomes over the overlap or common support, appropriately weighted by the propensity distribution score of smallholder farmers who adopted climate change adaptation strategies.

Table 1: Description of the Variables

Description of the variable	What the variable measures	How to measure it	Expected responses	Variable measurement type	Expected sign
Dependent variable					
Maize yield per hectare (ha)	it measures the level of maize productivity	By conducting surveys to determine the level of maize yield that a farmer has produced in kilograms (kgs) per the harvested area in hectares (ha)	Size of the land used for maize cultivation in hectares (ha) and the amount of harvest in kilograms (kgs)	Continuous variable	+
Independent Variable					
Climate Change Adaptation Strategies	Measures the adoption of the specific climate change adaptation strategy	By conducting surveys to identify whether a farmer adopts the particular adaptation strategy	1 = if a farmer adopts the adaptation strategy, 0 = otherwise	Categorical variable	+

The study also measured the individual influence of the adopted climate change adaptation strategies by performing a multiple linear regression model. The multiple linear equation model is presented as follows:

$$Y_i = \propto \ + \beta_i Z_i + \ldots + \ \mu_i$$

Where: Y_i = maize productivity, Z_i = climate change adaptation strategies, $\propto$ and β_i = parameters to be estimated and μ_i = stochastic error term

The climate change adaptation techniques used in this study were drawn from existing literature (Bedeke et al., 2019; Diallo et al., 2020; Kihupi et al., 2015; Ringo et al., 2018; Soglo & Nonvide, 2019), and smallholder farmers were asked to indicate whether they used the specific adaptation strategies by answering 'YES' or 'NO'. The analysis was done using the Stata 17 software to produce descriptive statistics in the form of frequencies and percentages. Table 1 provides a description of the variables used in the study.

Results of the Study

The analysis of the climate adaptation strategy adoption across various socioeconomic characteristics reveals several notable patterns among the smallholder farmers. Regarding gender, the majority of adopters were males, who constituted 89.40% of the total adopter population, compared to females who constituted 10.60%.

Table 2: Variation of Climate Adaptation Strategies across Socioeconomic Characteristics

Adoption Status	Variables		Frequency	Percent
	Gender			
	Male	Female		
Adopted	143	102	245	89.40%
Not Adopted	17	12	29	10.60%
	Marital Status			
	Married	Single		
Adopted	205	40	245	89.40%
Not Adopted	26	3	29	10.60%
	Extension Services			
	Received	Not Received		
Adopted	87	158	245	89.40%
Not Adopted	0	29	29	10.60%
	Credit Access			
	Access	No Access		
Adopted	85	160	245	89.40%
Not Adopted	3	26	29	10.60%
	Market Access			
	Access	No Access		
Adopted	203	42	245	89.40%
Not Adopted	25	4	29	10.60%
	Landownership Status			
	Owns	Rents		
Adopted	156	89	245	89.40%
Not Adopted	27	2	29	10.60%
	Climate Information			
	Access	No Access		
Adopted	195	50	245	89.40%
Not Adopted	26	3	29	10.60%
	Membership in Farmers' Associations			
	Member	Not Member		
Adopted	20	225	245	89.40%
Not Adopted	5	24	29	10.60%

This suggests a potential gender disparity in the adoption of climate adaptation strategies, with males being more inclined to adopt these measures compared to their female counterparts. Similarly, in terms of marital status, married individuals showed a higher adoption rate (89.40%) compared to single individuals (10.60%). This indicates that household dynamics and responsibilities may influence the decision-making process regarding climate adaptation strategy adoption, with married individuals possibly be more inclined to prioritize agricultural resilience measures.

Furthermore, the analysis of extension services utilization reveals a significant disparity in adoption rates based on access to extension services. Among those who received extension services, 89.40% adopted climate adaptation strategies while only 10.60% of those who did not receive such services adopted these strategies. This highlights the crucial role of extension services in facilitating the adoption of climate adaptation measures among smallholder farmers, emphasizing the importance of enhancing access to extension services to promote agricultural resilience. Additionally, similar patterns are observed concerning credit access and market access, with higher adoption rates among those with access compared to those without access, underscoring the influence of financial and market-related factors on the adoption of climate adaptation strategies.

Moreover, landownership status appears to influence the adoption of climate adaptation strategies, with higher adoption rates among landowners (89.40%) compared to renters (10.60%). This suggests that land tenure security may play a role in incentivizing smallholder farmers to invest in climate resilience measures, highlighting the importance of land tenure policies in promoting agricultural adaptation to climate change. Additionally, access to climate information emerged as a significant determinant of adoption, with a higher adoption rate observed among those with access to climate information (89.40%) compared to those without access (10.60%). This underscores the importance of disseminating accurate and timely climate information to empower smallholder farmers in making informed decisions regarding climate adaptation strategies.

Table 3 presents the characteristics of smallholder farmers involved in the study. The data comprises 274 observations for each variable. On average, the farmers were approximately 45 years old, with a minimum age of 22 and a maximum age of 85. In terms of education, the mean level was nearly 6 years of schooling, ranging from no formal education to a maximum of 16 years. The average household size among the farmers was approximately 4.5 individuals, with a minimum of 1 and a maximum of 11 members per household. Regarding farm-related variables, the average farm size for the sampled farmers was approximately 2.5 hectares, ranging from 1 to 6 hectares. Farmers had an average of around 7.6 years of experience in farming, with the minimum experience being 1 year and the maximum being 45 years. Finally, the average yield per kilogram of output was approximately 1495.35 kgs, with yields ranging from 106 to 9600 kgs per hectare. These findings provide insights into the demographic and agricultural characteristics of smallholder farmers in the study area, which are essential for understanding their farming practices and productivity levels.

Table 3: Characteristics of Smallholder Farmers

Variables	Observations	Mean	Min	Max
Age	274	44.78832	22	85
Education	274	5.959854	0	16
Household Size	274	4.540146	1	11
Farm size	274	2.551095	1	6
Farmers experience	274	7.609489	1	45
Output (Yield) per Kgs	274	1495.35	106	9600

Table 4 presents the variation in the adoption of climate change adaptation strategies among smallholder farmers. The percentages indicate the proportion of farmers who have adopted each strategy. The most commonly adopted strategy is changing planting dates, with 86.9% of farmers employing this approach. Short-duration maize varieties and drought-resistant maize varieties were also widely adopted with 67.15% and 56.2% of farmers utilizing these strategies, respectively.

Intercropping is practiced by 30.65% of farmers while minimal tillage is adopted by 48.9% of farmers. Agroforestry has the lowest adoption rate among the listed strategies with only 8.03% of farmers incorporating it into their practices. Similarly, irrigation and fertilizer use have relatively low adoption rates, with 7.2% and 16.4% of farmers utilizing these strategies, respectively. Crop rotation is adopted by 20.8% of farmers.

These findings highlight the varying degrees of adoption of climate change adaptation strategies among smallholder farmers, with some strategies being more widely embraced than others. Understanding the adoption patterns can inform targeted interventions and support initiatives aimed at enhancing the resilience of smallholder farming communities in the face of climate change.

Table 4: Variation in the Smallholder Farmers Adoption of Climate Change Adaptation Strategies

Climate Change Adaptation Strategies	Percentage
Drought-Resistant Maize Varieties	56.2
Intercropping	30.65
Minimal Tillage	48.9
Short-Duration Maize Varieties	67.15
Agroforestry	8.03
Fertilizer	16.4
Crop Rotation	20.8
Changing Planting Dates	86.9
Irrigation	7.2

Table 5: The Results on the Average Treatment Effects on the Treated (ATT)

Outcome variable	Matching Strategies	Adopting	Not adopting	ATT	t
Maize yield (kg/ha)	Nearest neighboring	245	22	228.653	2.512
	Radius matching	245	22	228.653	0.958
	Kernel Matching method	245	28	324.421	2.741

The Effects of Climate Change Adaptation Strategies on Maize Productivity

This section presents the results on the effects of the adopted climate change adaptation strategies on maize productivity among smallholder farmers. However, since the adoption status differs among smallholder farmers, the propensity score matching was used to estimate the average treatment effects on the adopters using the probit regression model as indicated in Table 5. Specifically, propensity score matching was adopted to form a balanced observational group of smallholder farmers between those who adopted and those who did not.

Therefore, in this study, the smallholder farmers who adopted the climate change adaptation strategies were termed as the treated group and those who did not adopt are termed as the control group. The matching of the groups was done by taking into consideration the individual propensity scores of the treatment group. The propensity scores were operationalized as the predicted probability of participation estimated from a probit regression of adopting the climate change adaptation strategies smallholder farmers based on the predictors.

Table 5 reveals the results of the average treatment effects (ATT) on the treated group which were estimated using kernel-based, radius and nearest-neighbor matching strategies. The results indicated that the average treatment effect (ATT) was significant at 228.653 and 324.421 from the use of the nearest neighbor and kernel matching methods only. This implies that the smallholder farmers who adopted the climate change adaptation strategies were able to produce from 228.653 to 324.421 more kilograms of maize than those who did not adopt the climate change adaptation strategies per hectare.

Moreover, results presented in Table 6 show the effects of climate adaptation strategies on maize productivity. Out of nine climate adaptation strategies, the crop rotation was not found to be significantly affecting maize productivity although it has positive relation.

Intercropping

The results in Table 6 indicated that with the influence of all other adaptation strategies held constant, as the smallholder farmers increase the use of intercropping as an adaptation strategy, say, by a unit, on average, maize yield will go up by 0.244 kilograms. This is because combining maize with other crops such as groundnuts, beans, and other crops like sorghum enables smallholder farmers to improve the nutrients of their soils and as a result, the yield of their crops will improve.

Drought Resistant Maize Varieties

The results indicate that, if the influence of all the other adaptation strategies is held constant, as the smallholder farmer increases the use of drought-resistant maize varieties, say, by a unit, on average, maize yield will increase by 0.103 kilograms. This is because drought-resistant varieties can sustain elevated temperatures and drought in the study area.

Irrigation

The results indicate that, on average, maize yield will increase by 0.527 kilograms when the smallholder farmer increases by a unit the utilization of irrigation as an adaptation strategy when all other strategies are held constant. This positive link exists because maize output is heavily dependent on water, therefore irrigation serves as a substitute for inconsistent and variable rainfall patterns.

Table 6: Multiple Linear Regression Estimation Outputs

Variables	Output
Drought resistance	0.103***
	(0.0142)
Intercropping	0.244***
	(0.0134)
Minimal tillage	0.274***
	(0.0105)
Short duration Varieties	0.808***
	(0.00771)
Fertilizer	0.508***
	(0.0077)
Agroforestry	-0.299***
	(0.021)
Changing planting	0.368***
	(0.00978)
Crop rotation	0.0931
	(0.0134)
Irrigation	0.527***
	(0.00742)
Constant	0.921***
	(0.0216)
Observations	245
R-squared	0.879

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Minimal Tillage

The results indicate that, with the influence of all other adaptation strategies held constant, as the smallholder farmers increase the use of minimal tillage as an adaptation strategy, say, by a unit, on average, maize yield will increase by 0.274 kilograms. This method minimizes soil disturbances, allowing the soil to retain nutrients and successfully promote maize growth.

Agroforestry

The results indicate that, with the influence of all other adaptation strategies held constant, as the smallholder farmers increase the use of agroforestry as an adaptation strategy, say, by a unit, on average, maize yield will decrease by 0.299 kilograms. This is because most smallholder farmers have small farm sizes, therefore, the combination of trees and maize in one single farm reduces farm space and yield expansion of the crop.

Additionally, Figure 1 illustrates the distribution patterns of propensity scores, with the upper half representing the treatment group (adopters) and the lower half representing the control group (non-adopters). Moreover, adopters were found to have an average maize yield of 1000 kg per year, whereas non-adopters had an average yield of 360 kg per year (*see* Table 7). This difference suggests a positive impact of adopting climate change adaptation strategies on maize productivity. The treatment group, comprising farmers who adopted these strategies, exhibited a significantly higher average yield per kilogram compared to the control group, indicating the effectiveness of adaptation strategies such as drought-resistant maize varieties, intercropping, minimal tillage, and changing planting dates.

Table 7: Comparison of Maize Yields between Adopters and Non-adopters of Climate Change Adaptation Strategies

Groups	Number of farmers	Average yield	Standard deviations	Control group description	P values
Adopters	245	1000	157.832	Control group characteristics	P<0.01
Non adopters	29	360	37.994	Control group characteristics	

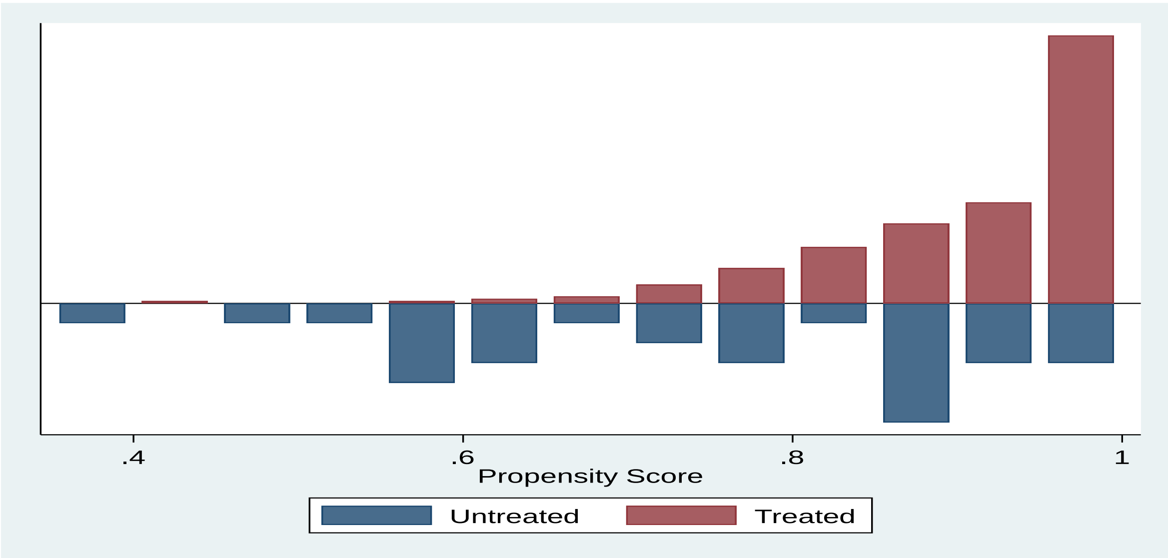

Figure 1: Distribution Pattern of the Propensity Score Matchi

To ensure balance between the treatment and control groups, the balancing property test was employed to estimate propensity scores, thereby equalizing observable background features. While the treatment group received training on the importance of climate adaptation, another group of smallholder farmers received no training to facilitate comparative analysis of variations. Subsequently, sensitivity analysis was conducted to establish the robustness of results obtained through matching methods. The results confirmed the satisfaction of joint support condition by examining the density distributions of estimated propensity scores for both the treatment and control groups.

The results in Figure 1 agree with those of Diallo et al. (2020), who found that, using the propensity score matching approach, smallholder farmers who used organic fertilizers and short-duration maize types produced higher yields than those who did not, except for modifying their planting dates, which did not create significant outcomes. Kuntashula et al. (2014) also found that the adopter of minimum tillage as an adaptation strategy had produced more yields than those who did not adopt using the propensity score matching method.

Conclusions and Policy Implications

This study explored how climate change adaptation strategies impact maize productivity among smallholder farmers. Unlike previous studies, it considered multiple adaptation strategies. The study concludes that adopting selected strategies leads to higher maize yields, particularly with drought-resistant maize varieties, irrigation, fertilizers, minimal tillage, adjusted planting dates and short-duration maize varieties. However, agroforestry adoption negatively affects maize yield. Therefore, promoting selected adaptive practices can significantly improve maize productivity in the study area.

The findings hold significant policy implications for enhancing maize productivity in regions vulnerable to climate change. Firstly, policymakers should prioritize the establishment of irrigation schemes in areas where water availability is limited. Access to irrigation can mitigate the adverse effects of erratic rainfall patterns and ensure consistent crop water supply, thus promoting stable maize yields. Furthermore, subsidies and incentives should be provided to smallholder farmers to facilitate the adoption of drought-resistant maize varieties. By promoting the cultivation of resilient crop varieties, policymakers can enhance farmers' adaptive capacity and reduce the vulnerability of maize production to climate-related risks.

Policies should prioritize the dissemination of knowledge and training on minimal tillage techniques, intercropping and adjusting planting dates to optimize crop yields while minimizing environmental degradation. Additionally, policymakers should invest in research and extension services to provide smallholder farmers with appropriate information and resources to effectively implement selected practices. By supporting the adoption of sustainable agricultural techniques, policymakers can contribute to long-term resilience in maize production and mitigate the impacts of climate change on food security.

To ensure the sustainability of climate change adaptation strategies in maize production, policymakers should prioritize the integration of agroforestry practices into agricultural policy frameworks. While agroforestry was found to negatively impact maize yields, its environmental benefits, such as soil conservation and biodiversity preservation, cannot be overlooked. Therefore, policies should still incentivize the adoption of agroforestry practices alongside other adaptation strategies to achieve a balance between environmental conservation and agricultural productivity. Additionally, longitudinal studies are recommended to monitor the effectiveness of adaptation strategies over time and to inform adaptive management approaches that can respond to evolving climatic conditions and agricultural challenge.

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