DETERMINANTS OF CLIMATE CHANGE ADAPTATION STRATEGIES AMONG EMERGING COMMERCIAL MAIZE FARMERS IN LIMPOPO PROVINCE, SOUTH AFRICA

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Abstract. Unless farmers mitigate climate-related risks, climate change will interrupt food security and agricultural sustainability. The study aimed to analyse the strategies adopted by emerging maize farmers in the Limpopo province of South Africa to respond to climate-related risks to ensure sustainable production, food security, and improved income. Primary data were collected from 288 randomly selected farmers through a semi-structured questionnaire. Descriptive statistics and a fractional response model were used to analyse the data in STATA version 14. The analysis results revealed that education, the type of labour employed, reduction in the area of cultivated farmland due to climate-related risks, and income from farming diversification constituted the determinants of climate change adaptation strategies among the study area's emerging commercial maize farmers. The study recommends that the government develop policies based on the aforementioned determinants to promote the adoption of climate change adaptation strategies among emerging commercial farmers for sustainable food production and improved income.
Keywords: *climate-related risks, fractional-response-model, hired labour, crop-diversification, cultivated land*

Introduction

Climate change is expected to have severe consequences for agriculture in South Africa, particularly in the Limpopo and North-West provinces, where significant yield and revenue losses are projected by 2080 (Turpie & Visser, 2013). The major climate-related risks include hailstorms, flooding, frequent droughts, and unpredictable rainfall patterns (Mengistu, 2011). Climate change results from shifting precipitation patterns and rising temperatures, which present increasing challenges for farmers worldwide (Ortiz-Bobea, 2018). According to Ceccarelli et al. (2010), these climatic changes are already contributing to food insecurity.

Cammarano et al. (2020) emphasize the need to assess adaptation strategies that can mitigate the adverse impacts of climate change. This study aims to analyze the determinants of climate change adaptation strategies adopted by farmers to enhance food security and improve income. Climate change adaptation refers to the actions implemented to respond to changing environmental conditions, reduce extreme weather challenges, and capitalize on emerging opportunities (Nzeadibe et al., 2011).

The agricultural sector is highly vulnerable to climate change, which threatens food security (Wu et al., 2021). Nkonya et al. (2018) highlight that climate change significantly affects smallholder farmers' livelihoods and food availability. Addressing food security in South Africa requires sufficient maize production, as maize is the country's staple food and a key crop globally (Neupane et al., 2022; Chapoto & Jayne,

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2019). Haile et al. (2022) further underscore that maize is not only a staple but also a high-calorie source for human consumption and a crucial raw material for industrial products. Consequently, smallholder maize farmers must adopt climate change adaptation strategies to maintain high yields and contribute to both food security and the maize value chain.

Climate change poses a threat to maize production and the cultivation of other field crops that rely on water availability (Mulungu & Ng'ombe, 2019). When farmers produce surplus maize beyond their consumption needs, they engage in market sales (Mango et al., 2018). However, smallholder farmers often face market access challenges, prompting efforts to address perceived market failures (Chapoto & Jayne, 2019). Haile et al. (2022) argue that without environmental considerations, smallholder farmers will struggle to participate in markets and benefit from commercialization. Effective climate adaptation strategies can enhance productivity under adverse environmental conditions, ensuring both income generation and food security. Tafesse et al. (2023) highlight household market participation as a key strategy for poverty reduction and improved farmer income. Cammarano et al. (2020) project that adopting climate change adaptation strategies in maize farming in South Africa could increase net farm returns by 20–26% and reduce poverty rates by 20%. Income diversification, as a climate change adaptation strategy, plays a crucial role in sustaining farming businesses. For instance, Abdulai et al. (2018) report that Ghanaian cocoa farmers diversify their income sources by cultivating non-cocoa crops.

Understanding the impact of climate change on maize production is critical for both national and global economic stability (Wu et al., 2021). Sarkar and Padaria (2016) warn that climate change-induced agricultural declines could negatively affect national economies and livelihoods. Adaptation to climate change is widely recognized as a crucial strategy for managing climate-related risks (Field & Barros, 2014). Hellin et al. (2012) emphasize the need for adaptation measures to be integrated into policy and management decisions at national and international levels.

Woods et al. (2017) highlight the importance of studying climate adaptation across various contexts to address diverse climate risks. Education plays a vital role in adaptation, as it enhances individuals' capacity to prepare for and respond to climate change impacts (Feinstein & Mach, 2020). Lee et al. (2015) advocate for investments in primary and secondary education to increase climate change awareness. Mengistu (2011) asserts that improving farmers' knowledge, forecasting abilities, and management skills can significantly enhance their adaptation efforts.

To sustain crop yields, farmers must adopt appropriate adaptation strategies tailored to the expected climatic conditions (Xu et al., 2016). Nkonya et al. (2018) project that without adaptation, maize yields in sub-Saharan Africa could decline by 20% by 2050. Jayne et al. (2018) note that African farmers are actively seeking adaptation strategies to cope with climate change. Irrigation is a key adaptation measure, as it supplements rainfall during dry periods and extends the growing season (Calzadilla et al., 2014). Additionally, diversification strategies contribute to climate-smart agriculture and enhance food security (Arslan et al., 2018).

Deressa et al. (2011) identify financial constraints and labour shortages as key barriers to effective climate adaptation. However, Day et al. (2019) highlight the availability of several low-cost adaptation options. Given that agriculture employs a large proportion of the labour force in sub-Saharan Africa, climate change is expected to have a disproportionately severe impact on the region (Kuntashula et al., 2014).

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Shayegh and Dasgupta (2022) warn that declining agricultural productivity due to climate change could trigger price shocks, increasing labour demand in certain sectors. The financial burden of climate adaptation is expected to rise in the coming years (Lutz et al., 2014), necessitating sustainable income generation. Moser and Satterthwaite (2008) observe that low- and middle-income communities face greater adaptation challenges compared to wealthier societies.

Given these challenges, climate change adaptation strategies must be prioritized in the smallholder farming sector to mitigate adverse impacts. This study aims to analyze the adaptation strategies used by smallholder maize farmers to address climate-related risks. The findings will inform policy recommendations to enhance maize production, promote sustainable food security, and improve farmer incomes.

Material and methods

Study area

According to Statistics South Africa (StatsSA, 2021), Limpopo Province has an estimated population of approximately 5,926,724 (*Fig 1*). The province's demographic structure indicates that males dominate the age group of 1 to 29 years, whereas females constitute a larger proportion of the population aged 30 years and older (Limpopo Socio-Economic Review and Outlook, 2019).

Over time, educational attainment in Limpopo has improved. In 2010, the province had approximately 499,000 illiterate individuals, but this number declined to 330,000 by 2020. The population with tertiary education is estimated at 427,526, while around 835,465 individuals have completed matric (Limpopo Socio-Economic Review and Outlook, 2019). Despite improvements in education, the province has faced economic challenges. The unemployment rate increased between January 2020 and September 2021. However, the agricultural sector made a positive contribution to the province’s economy, adding 0.4 percentage points to Limpopo's gross domestic product (GDP) in 2020 (Limpopo Socio-Economic Review and Outlook, 2019).

Sampling technique

Simple random sampling was used to select the respondents for the study. The study on emerging commercial maize farmers in the Limpopo province. Mabaya et al. (2011) define emerging farmers as those farmers in the process of graduating from being subsistence farmers to becoming commercial farmers. A suitable sample to represent the population was calculated using the formula provided by Krejcie and Morgan (1970) (*Eq. 1*). There were 354 emerging commercial maize farmers in the province, and of these 288 participated in the study (*Table 1*).

$$S = X^2 \ NP\ (1–P)/d^2\ (N–1) + X^2P\ (1–P) \quad \text{(Eq.1)}$$

where: S = required sample size; X = Z value (e.g. 1.96 for 95% confidence level); N = population size; P = population proportion (expressed as a decimal) (assumed to be 0.5 (50%); d = degree of accuracy (5%), expressed as a proportion (.05). It is margin of error.

$$S = 1.96^2 \times 354 \times 0.5\ (1–0.5)/0.05^2\ (354–1) + 1.96^2 \times 0.50\ (1–0.50) = 288 \quad \text{(Eq.2)}$$

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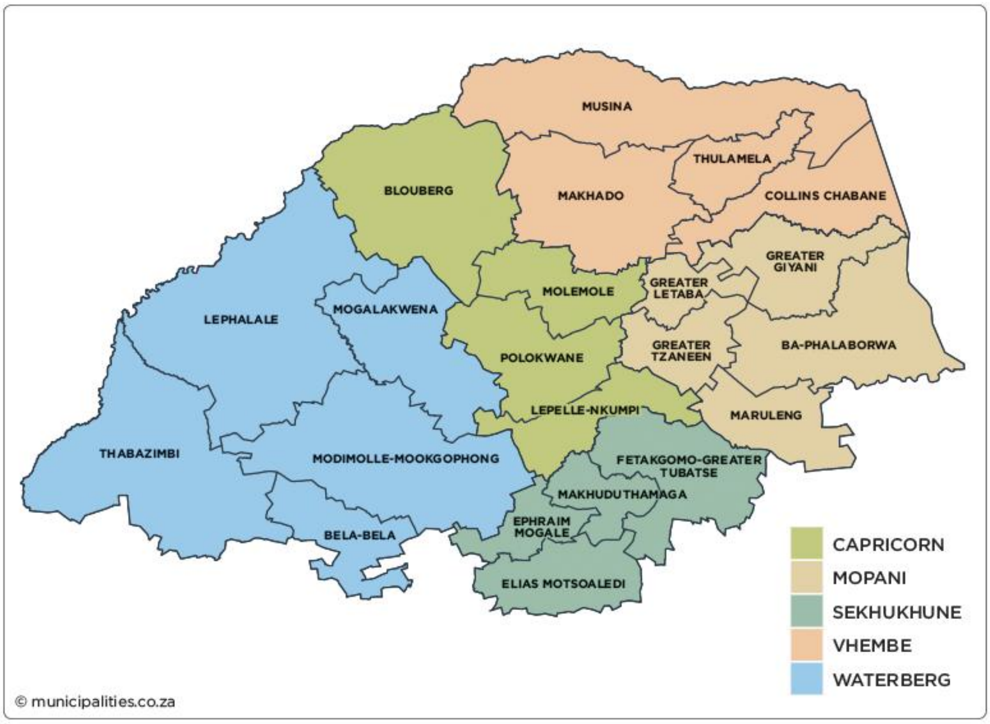

Figure 1. *Map of Limpopo province in South Africa. Source: https://municipalities.co.za/provinces/view/5/Limpopo (accessed: 13 September 2024)*

Table 1. *The study sample per district*

District	Male	Female	Total
Vhembe	47	55	102
Mopani	54	27	81
Sekhukhune	37	33	70
Waterberg	14	8	22
Capricon	9	4	13
Total	**161**	**127**	**288**

Source: Data from the study

Data collection and analysis

The data was collected over two months, from December 2019. A semi-structured questionnaire and an interview schedule comprising open- and closed-ended questions were used for data collection. The data were collected with the consent of each farmer participating in the study, with consent forms having been prepared in accordance with the ethics policy of the University of South Africa. Cross-sectional data were used to respond to the research questions formulated for the study. The collected data were statistically analysed by means of fractional logistic regression in STATA version 14 to estimate the factors exerting a significant effect on the use of climate change adaptation strategies employed by farmers.

The dependent variable and explanatory variables used for the analysis and the model specification are presented in *Table 2*.

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The fractional response model of Oberhofer and Pfaffermayr (2012) is given below:

$$E(y_i I x_i) = G(x_i \beta),\ I = 1,\ldots,N \quad \text{(Eq.3)}$$

where $0 \leq y_i \leq 1$ represents the dependent variable (proportion of adaptation strategies employed) and the ($1 \times k$ vector) x_i refers to the explanatory variables of observation i. G(.) is a distribution function like the logistic function $G(z) = \exp(z)/(1 + \exp(z))$, which maps Z to the (0,1) interval. The observable variable Y is equal to the latent variable whenever the latent variable is above zero (Wooldridge, 2009).

$$l_i(\beta) = y_i \log[G(x_i\beta)] + (1\text{-}y_i)\log[1 - G(x_i\beta)] \quad \text{(Eq.4)}$$

In this formulation of the likelihood function, the number of draws (referring to the number of climate change adaptation strategies used by each farmer) drops out because it does not depend on the parameters.

Table 2. *Variables used in the fractional response model*

Dependent variable	Variable label	
Y	Proportion of adaptation strategies employed by an emerging commercial farmer	
Independent variables		**Expected effect**
X_1	Gender (Male = 1, Female = 0)	Positive
X_2	Household size (number)	Positive
X_3	Marital status (Married = 1, if not married = 0)	Positive
X_4	Educational level (No formal education = 1, Primary education = 2, Secondary education without matric = 3, Matric = 4, Tertiary = 5)	Positive
X_5	Type of labour (No labour = 0, Family labour = 1, Hired labour = 2, Both family and hired labour = 3)	Positive
X_6	Belief that adaptations can manage climate related risks (CRR) (Yes = 1, No = 0)	Positive
X_7	Reduction in the area of cultivated farmland because of climate-related risks (Yes = 1, No = 0)	Negative
X_8	Income from diversification per year	Positive

A two-part model that takes account of a large number of boundary values that are equal to one can be considered as an alternative.

$$y^* = \begin{pmatrix} 0\ if\ y & ἑ[0,1) \\ 1\ if y & = 1 \end{pmatrix} \quad \text{(Eq.5)}$$

Assume for the first part of the model that $P(y_i^* = 1 l x_i) = P(y_i = 1 l\ x_i) = G(x_i y)$, where $G(x_i y)$ denotes the cumulative logistic distribution function. The second part of the model is the fractional response model, which refers to observations y_i ἑ[0,1)

The two-part model is specified as:

$$E[y_i\ l\ x_i] = P(y_i^* = 0 l x_i)\ E[y_i\ l\ x_i,\ y_i^* = 0] + P(y_i^* = 1 l x_i) = (1 - G(x_i y))G(x_i\beta) + G(x_i y) \quad \text{(Eq.6)}$$

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The marginal effects of the independent variables can be obtained as follows:

$$\partial E[y_i | x_i] / \partial x_{ij} = (\partial P(y_i^* = 1|x_i) / \partial x_{ij}) (1 - E[y_i | x_i, y_i^* = 0] + (1 - P(y_i^* = 1|x_i)) \partial E[y_i | x_i, y_i^* = 0] / \partial x_{ij} \quad \text{(Eq.7)}$$

The statistics to determine the model fit include the Wald chi2, Prob. > chi2, Pseudo R2 and the VIF (Variance Inflationary Factor) from Multicollinearity test results.

Results

Table 3 presents the demographic characteristics of farmers. The results indicate that 56% of the respondents were male, while 44% were female. Regarding the age of the farmers, 6% of the respondents were between 18 and 35 years, 18% were aged 36 to 50 years, 30% were between 51 and 60 years, and the majority (46%) were over 60 years old. Regarding household size, 7% of the respondents had fewer than three household members, 39% reported household sizes between three and five persons, 46% had between six and ten members, and 8% had households with more than ten individuals. Marital status data indicate that 71% of the respondents were married, while 29% were single. In terms of educational attainment, 16% of the respondents had no formal education, 25% had completed primary education, 26% had attained secondary education without matriculation. Additionally, 16% had successfully matriculated, and 17% held tertiary education certificates.

Table 3. *Demographic characteristics of farmers (n = 288)*

Gender	**Frequency**	**Percentage**
Male	161	56
Female	127	44
Age group		
18- 35 Years	18	6
36-50 Years	52	18
51- 60 Years	87	30
> 60 Years	131	46
Marital status		
Married	204	71
Single	84	29
Household size		
<3	21	7
3- 5	112	39
6- 10	132	46
>10	23	8
Educational level		
No formal education	46	16
Primary education	72	25
Secondary education without matric	75	26
Matric	45	16
Tertiary	50	17

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Table 4 presents the socioeconomic characteristics of farmers. The findings indicate that 90% of the respondents were not formally employed and relied solely on farming, whereas 10% were engaged in both farming and formal employment. Concerning labour utilization, 51% of the respondents employed hired labour, 16% relied on family labour, 25% used a combination of both, and 8% did not employ labourers. The availability of labour to perform farming activities is important because farm workers can influence adaptation to climate change. Regarding perceptions of climate change, most of the respondents (93%) believed that climate change adversely affects farming activities, while 7% did not perceive it as a challenge. Concerning the impact of CRR on farm utilization, 79% of the respondents reported that the proportion of cultivated land remained unchanged despite the presence of CRR, while 21% reported that their farmland utilisation had decreased as a result of CRR.

Table 4. *Socio-economic characteristics of farmers (n = 288)*

Characteristic	Frequency	Percentage
Occupation of the respondents		
Only farming	260	90
Formal employment and farming	28	10
Type of labour		
Hired labour	146	51
Family labour	45	16
Both hired, and family labours	73	25
No labour	24	8
Believe that climate change has a negative impact		
Yes	267	93
No	21	7
CRR decreases the % of cultivated farmland		
Yes	61	21
No	227	79

Table 5 presents the percentage of farmers who adopted various climate change adaptation strategies in the study area. The findings reveal that 99% of the respondents employed crop diversification as a key strategy to mitigate climate-related risks, while 98% relied on irrigation to address rainfall shortages. Additionally, 90% of farmers practiced crop rotation as an adaptation measure. Regarding soil fertility management, 60% of the respondents used improved seed varieties, 32% applied chicken and/or cattle manure, and 24% adopted intercropping to enhance resilience against climate risks. Approximately 18% practised Climate-Smart Agriculture by incorporating crop residue into the soil, while 9% used compost manure to enhance soil fertility for maize production. Other adaptation measures included changing planting dates (8%) and implementing staggered planting within a season. About 6% of farmers irrigated their crops either very early in the morning or very late in the evening to mitigate the effects of high day temperatures, while 5% planted trees around the farm to protect crops from wind speed and soil erosion. Some respondents purchased farming insurance as a climate risk mitigation strategy.

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Table 5. *Adaptation strategies used in the study area*

Category of adaptation strategies	Adaptation strategy
Crop diversification	99%
Irrigation	98%
Crop rotation	90%
Good seed variety	60%
Chicken and/or cattle manure	32%
Intercropping	24%
Crop residue incorporation	18%
Compost	9%
Change times of planting	8%
Planting different size of maize per season	8%
Change time of irrigation	6%
Planting trees to protect against soil erosion and/or for oxygen	5%
Purchased farming insurance	3%
Ploughing by hand	2%
Using leaves of the plant for pest control (leaves of moringa, pawpaw, or aloe)	2%
Pray	1%
Fire break	0.7%
Planting of windbreaks and shelter belts	0.3%
Curve furrow	0.3%
Use of salts for moisture	0.3%
Mixture of African beer and chills	0.3%

Less common adaptation practices included ploughing with hand hoes (2%) and using botanical pesticides such as moringa, pawpaw, or aloe trees or plants, to control insect pests. A small proportion of farmers relied on spiritual interventions, such as prayer, while 0.7% established fire breaks to safeguard against bushfires. To mitigate flood risks, 0.3% of farmers constructed curved furrows for soil conservation, particularly for farms located in steep or valley areas. Similarly, 0.3% reported using a mixture of African beer and chilli as a natural pesticide for maize pest control.

Fractional response model on the determinants of climate change adaptation strategies among maize farmers

The results of the Chi2 test were statistically significant ($p < 0.01$), indicating that the model fits the data very well. The variance inflation factors (VIF) was used to check for the presence of multicollinearity between independent variables. The results indicate that the mean VIF was 1.07, less than the acceptable maximum of 10, and hence the conclusion that there was no multicollinearity between the independent variables included in the model. The full model results and specification tests are presented in *Table 6*.

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Table 6. *Fractional response model on the determinants of climate change adaptation strategies among maize farmers*

Variables	Coef.	Std. Err.	P > |z|	dy/dx
Gender	-0.061	0.044	0.167	-0.010
Household size	0.001	0.006	0.833	0.000
Marital status	0.073	0.047	0.122	0.012
Education	0.036	0.016	0.025**	0.006
Type of labour	0.052	0.022	0.022**	0.009
Belief that adaptations can manage CRR	0.033	0.054	0.542	0.005
CRR reduced the proportion of cultivated farmland	-0.069	0.039	0.083*	-0.011
Income from farming diversification	0.082	0.032	0.011**	0.014
Cons	-1.83	0.191	0.000	
Number of observations	288			
Wald chi2(8)	40.57			
Prob. > chi2	0.000			
Pseudo R2	0.002			
Multicollinearity test	Mean VIF = 1.07			

*** Significant at 1%; ** Significant at 5%; *Significant at 10%

The results in *Table 6* indicate that the coefficient linked to education was positive (0.036) and statistically significant ($p < 0.05$). A one-unit increase in education led to a 0.6% increase in the proportion of adaptation strategies employed. The coefficient associated with the type of labour is positive (0.033) and statistically significant ($p < 0.05$). The results from the descriptive statistics indicate that 51% of the farmers employed hired labour. A unit increase in hired labour is associated with a 0.9 percentage increase in the proportion of adaptation strategies employed by the farmer, *ceteris paribus*. The coefficient associated with a reduction in the area of cultivated farmland as a result of CRR (0.069) is negative and statistically significant ($p < 0.10$). A unit increase in the reduction of cultivated farmland due to CRR is associated with a 1.1% decline in the proportion of adaptation strategies employed, *ceteris paribus*. The coefficient associated with income from farming diversification had a positive (0.083) and statistically significant ($p < 0.5$) influence on the proportion of adaptation strategies employed. A unit increase in income from farming diversification is associated with a 1.42% increase in the proportion of adaptation strategies employed, *ceteris paribus*.

Discussion

All adaptation strategies employed by farmers in the study area aimed to enhance food security and generate income through the sale of maize. Agricultural adaptation to climate change is directly linked to improving food security (Hellin et al., 2012). The findings of this study align with existing literature. Woods et al. (2017) identified diversification, crop rotation, intercropping, irrigation, and pesticide use as key climate change coping strategies among farmers. Similarly, a study conducted in Swaziland by Oseni and Masarirambi (2011) found that rainwater harvesting, soil conservation practices, intercropping, early-maturing maize varieties, and crop diversification can mitigate the effects of climate change while enhancing household food security. Tesfaye et al. (2015) emphasized the necessity of climate adaptation strategies to ensure food security for the growing population in sub-Saharan Africa.

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Notably, the study also identified the use of salt to retain soil moisture during periods of low rainfall. However, this practice is classified as maladaptation, as excessive salt application degrades soil quality. Rath et al. (2016) underscored the importance of understanding the impact of salinity on soil microbial communities, while Akanbi et al. (2021) recommended strengthening and supplementing effective adaptation strategies to enhance resilience and avoid maladaptation.

The level of education among farmers in Limpopo province was positively associated with the adoption of climate adaptation strategies. This suggests that higher literacy rates among farmers lead to increased implementation of climate change adaptation measures. These findings are consistent with those of Lutz et al. (2014), who found that education plays a crucial role in reducing disaster vulnerability and improving adaptation potential. Likewise, Feinstein and Mach (2020) observed that societies with a well-developed education infrastructure are better equipped to implement climate adaptation mechanisms.

Labour type also influenced the adoption of adaptation strategies. The study found a positive relationship between the type of labour employed and the number of adaptation strategies used by farmers. However, contrary findings were reported by Amfo and Ali (2020), who found that farmers employing hired labour adopted fewer adaptation strategies than those relying on family labour. Similarly, Oluwatusin (2014), in a study conducted in Nigeria, observed that the majority of farmers exclusively used hired labour for climate change adaptation.

The reduction of cultivated farmland due to CRR had a negative relationship with the number of adaptation strategies adopted. Brown et al. (2008) reported similar findings in Scotland, where shifts in land use impacted anticipatory climate adaptation measures. Additionally, Speelman et al. (2010) found that water shortages during the dry season in Limpopo province resulted in reduced cultivated areas, further limiting farmers' ability to implement adaptation strategies.

Most farmers in the study area cultivated maize alongside other crops. The results indicated a positive relationship between income diversification in farming and the number of adaptation strategies employed. This suggests that increased income from diverse farming activities enhances farmers' ability to adopt climate adaptation measures. Similar findings were reported by Amfo and Ali (2020) in a study on cocoa farmers in Ghana, where diversified income sources improved climate adaptation efforts. Additionally, Ahmad and Afzal (2020) highlighted a direct link between net income and climate adaptation strategies.

Conclusion

The study concludes that policies and farmer support programmes aimed at enhancing climate change adaptation strategies among emerging commercial maize farmers should prioritize improving farmers’ education, promoting the use of hired labour, and facilitating income diversification. The findings confirm the hypothesis that education has a significant positive association with climate adaptation strategies. Investing in farmer education would not only enhance the success of their agricultural enterprises but also mitigate the environmental impacts of climate change. Therefore, resources should be allocated to training workshops designed to equip farmers with knowledge on climate change adaptation and best farming practices. These training

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initiatives should be conducted by key agricultural stakeholders responsible for disseminating farming-related information in the study area, such as the Department of Land Reform and Rural Development.

The study also validates the hypothesis regarding the influence of labour type on climate change adaptation. The findings indicate that farmers who employed hired labour were more likely to adopt a greater number of adaptation strategies. Hired labour is preferred over family labour because it adheres to structured working hours and contributes to the efficient implementation of climate adaptation measures. Additionally, the use of hired labour enables farmers to adopt multiple adaptation strategies simultaneously, thereby minimizing crop losses, improving yields, and ensuring profitability despite labour costs.

Furthermore, the study confirms that a reduction in cultivated farmland due to CRR negatively impacts the adoption of adaptation strategies. This finding supports the hypothesis that CRR constrains the proportion of cultivated farmland, thereby limiting farmers' capacity to implement effective adaptation measures. Finally, the results affirm that income from farming diversification is positively associated with the adoption of climate change adaptation strategies, highlighting the importance of economic resilience in ensuring sustainable agricultural practices.

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