frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 25 June 2024
DOI 10.3389/fsufs.2024.1376868

Check for updates

OPEN ACCESS

EDITED BY
Farirai Rusere,
University of the Witwatersrand, South Africa

REVIEWED BY
Ephias Mugari,
University of Venda, South Africa
Raymond Mugandani,
Midlands State University, Zimbabwe

*CORRESPONDENCE
Aurillia Manjella Ndiwa
aurillia.manjella@gmail.com

RECEIVED 26 January 2024
ACCEPTED 03 June 2024
PUBLISHED 25 June 2024

CITATION
Ndiwa AM, Mburu J, Mulwa R and Chumo C (2024) Determinants of climate change adaptation strategies and intensity of use; micro level evidence from crop farmers in Kenya. *Front. Sustain. Food Syst.* 8:1376868. doi: 10.3389/fsufs.2024.1376868

COPYRIGHT
© 2024 Ndiwa, Mburu, Mulwa and Chumo. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Determinants of climate change adaptation strategies and intensity of use; micro level evidence from crop farmers in Kenya

Aurillia Manjella Ndiwa[1]*, John Mburu[1], Richard Mulwa[2] and Chepchumba Chumo[3]

[1]Department of Agricultural Economics, University of Nairobi, Nairobi, Kenya, [2]Center for Advanced Studies in Environmental Law and Policy (CASELAP) and School of Economics, University of Nairobi, Nairobi, Kenya, [3]Department of Agricultural Economics, Moi University, Eldoret, Kenya

Climate change and its negative impacts pose a threat to crop production in Kenya. However, climate change adaptation strategies have the potential to address the challenges faced by crop farmers. Despite this, there is limited literature to inform policy on the best interventions to help farmers deal with climate issues. This study assessed the determinants of climate change adaptation strategies and the intensity of their use among 723 crop farmers in Busia County, Kenya, selected through a multistage sampling technique. Data were collected using a structured questionnaire and analyzed using principal component analysis (PCA), multinomial logit regression, and the ordered probit model. The climate change adaptation strategies were categorized into crop diversity, cover crops, use of drought-resistant crops, and irrigation. According to the results, the factors contributing to the uptake of the different adaptation strategies were age, household size, access to credit, training access, off-farm income, group membership, frequency of receiving climate change information, and extension services. The major factors influencing the uptake of multiple climate change adaptation strategies were access to credit and off-farm income. The study shows that certain adaptation strategies, such as using cover crops, do not require credit and offer an important option in an environment with limited resources. On the other hand, adaptation measures such as irrigation demand financial resources for farmers to implement them, highlighting the importance of information and awareness in adopting adaptation strategies and the supportive role of financial resources, particularly for adopting multiple strategies. Therefore, this study suggests implementing policies and interventions that encompass knowledge-based strategies such as extension services, training, climate change education, group participation, and financial mechanisms like income generation activities and access to credit. These integrated strategies will enable farmers to adopt various climate change adaptation methods for sustainable crop production.

KEYWORDS

climate change, adaptation strategy, determinant of adaptation, small scale farmers, ordered probit model, multinomial logit regression

1 Introduction

The impact of climate change is felt all over the world, and small-holder farmers face more risks due to unpredictable weather patterns. Temperatures continue to rise in the world, and globally, median temperatures are estimated to rise by 4.1°C by the end of the 21st century (Adhikari et al., 2015). Increases in temperature and other extreme climate events affect crop productivity, and projections from previous studies (Chen and Gong, 2021; Molotoks et al., 2021; Mulungu et al., 2021) indicate more adverse effects in the future. According to Singh and Purohit (2014), by 2030, maize production in Southern Africa will have reduced by up to 30%, and yield in developing countries might drop by an average of 17.5%. East Africa is not different, as the temperature is projected to rise faster than the rest of the world (Niang et al., 2014). In Kenya, global warming is projected to negatively impact agriculture between 2020 and 2040, as Ochieng et al. (2016) reported in their study on the impact of climate change during the same period.

Kenya's economy is dependent on agriculture, and its growth is key, as 26% of the gross domestic product (GDP) comes directly from agriculture and 25% indirectly through other sectors like manufacturing (World Bank, 2020). However, the economy faces challenges due to climate change, which is expected to reduce the GDP by 2.4% annually (GOK, 2018a,b). Additionally, the cost of drought is estimated at 8.0% of GDP every 5 years, and the cost of floods is estimated at 5.5% of GDP every seven years (Government of Kenya, 2017). Crop production is the major contributor to the agricultural GDP (78%), yet it is characterized by low productivity. Low crop productivity is worsened by different shocks, especially climate-related shocks, which affect the whole food system (Campbell et al., 2016), as 98% of the crop system in Kenya is rain-fed and highly susceptible to climate change (Government of Kenya, 2017).

The direct effect of climate change on crop productivity affects household livelihoods, especially food and nutrition security. According to Food Agriculture Organization (2023), climate change is the major driver of food insecurity and malnutrition worldwide and will continue to rise. Nelson et al. (2009) highlighted the potential for climate change to cause an increase in global hunger and malnutrition by 2050, and in Africa, climate change is estimated to push around 122 million people into hunger by 2050 (FAO, 2015). East Africa has also experienced a higher frequency of extreme droughts in recent decades, which is projected to continue. These droughts negatively impact food production, leading to widespread hunger and malnutrition. In Kenya, the decline in rainfall has been reported over the past few decades (Ochieng et al., 2016), which has negatively impacted agricultural productivity, leading to increased food insecurity and malnutrition, particularly among small-scale farmers' households.

Crop productivity can be improved through the use of climate change adaptation strategies (Reidsma et al., 2010; Lobell, 2014; GOK, 2018a,b). These strategies vary across various factors, such as soil, water, and input-related climate change adaptation strategies. Previous studies (Mabe et al., 2014; Belay et al., 2017; Francis et al., 2017; Asfaw et al., 2019; Ojo and Baiyegunhi, 2020; Kogo et al., 2022) have identified various adaptation measures, including timely planting, irrigation, tree planting, and the adoption of improved crop varieties. Timely planting involves changing the planting calendar by either planting early or late, depending on the weather pattern (Asfaw et al., 2019). Irrigation involves storing and providing a reliable water supply for crops during erratic rainfall patterns, prolonged droughts, and water scarcity, ensuring agricultural productivity even during dry periods (Francis et al., 2017). Tree planting is incorporated within or along the edges of the farm to help regulate temperatures, provide shade to crops, and help prevent soil erosion (Belay et al., 2017). Improved seed variety involves different crop varieties tailored to certain climatic conditions that help the farmers better cope with challenges such as erratic rainfall patterns associated with climate change. However, these strategies can vary, depending on locality and other socioeconomic factors. For example, in some regions, adaptation strategies may be tailored toward soil conservation or water management. This variation is evident not only between countries but also within different regions within the same country (McKinley et al., 2021). The simultaneous use of multiple strategies has been associated with improved yields (Teklewold et al., 2019). Moreover, employing a combination of strategies can sometimes complement or substitute each other to effectively address the impacts of climate change.

While existing research has explored climate change adaptation strategies in agriculture (Gebru et al., 2020; Saddique et al., 2020; Getahun et al., 2021; Mogaka et al., 2021; Kumar et al., 2023; Molla et al., 2023; Moniruzzaman et al., 2023), there remains a critical gap in understanding the uptake and determinants of employing multiple adaptation strategies. This limitation restricts the ability to optimize agricultural productivity, ensure sustainable crop production, and build robust household resilience in the face of a rapidly changing climate (Francis et al., 2017). Furthermore, the potential of emerging adaptation strategies, whether novel or specific to particular localities, requires further exploration to enrich the existing knowledge base. These unique approaches hold significant promise for advancing climate resilience but remain largely undocumented.

This study aims to fill existing gaps by comprehensively evaluating climate change adaptation strategies, including their determinants and the intensity of use. Understanding these strategies and the factors driving them is essential for designing targeted programs that address the specific needs of those affected. By bridging these knowledge gaps, the study seeks to contribute significantly to the field of climate change adaptation in agriculture, paving the way for more resilient and sustainable agricultural practices in response to climate change.

2 Methodology

2.1 Study area

The study was conducted in Busia County, located in the western part of Kenya (Figure 1). Specifically, it focused on two regions: Teso South and Funyula (Samia) sub-counties, where agriculture has been significantly affected by climate change. The county covers an area of ∼1,695 km^2 and lies between longitude 33.91°E and 34.44°E and latitude 0.03°S and 0.76°N. Busia largely depends on rainfed agriculture, which provides employment for ∼78% of the population and remains the main source of income

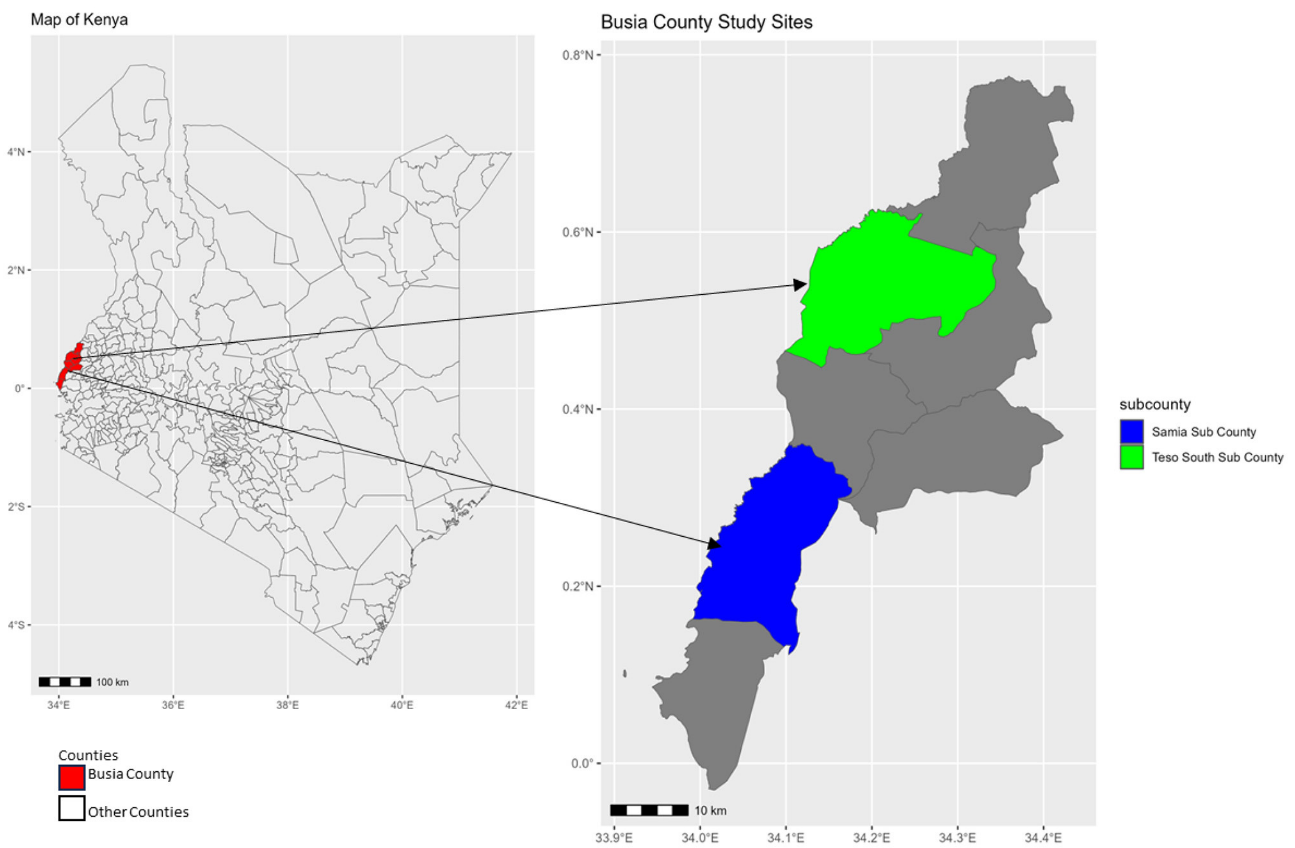

FIGURE 1
Map of Busia County. Source: Author.

for ∼65% of the populace. Most of the farmers are small-holders with an average acreage of 1.71 (MoALF, 2014; GOK, 2018a,b). The major crops cultivated include maize, millet, beans, sweet potatoes, cassava, cotton, tobacco, vegetables, fruits, and sugarcane (GOK, 2018a,b). In recent times, the county has experienced low crop productivity due to extreme climate change and events (MoALF, 2014; GOK, 2023), with anticipation of more negative impacts on maize and sorghum, as reported by GOK (2023). Though sorghum is highly known to withstand the effects of climate change, recent studies (Mohammed and Misganaw, 2022; Niyibigira et al., 2024) have reported a negative impact of climate change on sorghum. Some of the events in the county include increased temperatures, intense rains, floods, and frequent droughts (MoALF, 2014; GOK, 2023).

2.2 Data collection and sampling procedures

A multistage sampling technique was used in this study. In the first stage, Busia County was purposefully selected due to its experience of low yields coupled with high poverty levels and elevated malnutrition resulting from the negative impact of climate change (GOK, 2018a,b). In the second stage, two sub-counties, Teso South and Funyula (Samia), were purposefully selected based on KII with Ministry of Agriculture personnel. These sub-counties have been significantly affected by climate extremes and engage in diverse agricultural enterprises. For the third and final stage, a systematic random sampling approach was used to select households from the sampling frame (a list of registered farmers from the Ministry of Agriculture). The sample size was calculated using Cochran's formula (Cochran, 1977) as shown in Equation 1.

$$n = \frac{Z^2 \times (p)(q)}{(d)^2}, \quad (1)$$

where the Z = value of the selected alpha is 2.58 at a 99% confidence level (Singh and Masuku, 2014), while p is the estimated proportion of the study population that has the attribute of interest (50% of the households are assumed to be using climate change adaptation strategies), and q is $(1 - p)$. d is the acceptable margin of error for proportion, which is estimated at 0.05 (Bartlett et al., 2001), giving a sample size of 668. The sample was then increased by 15% to account for a non-response rate, which is supported by Irene et al. (2022), making it a total of 768 households. Based on the number of households from each sub-county, as listed in the sampling frame, proportionate sampling was used to determine the sample size to be drawn from each sub-county. Using systematic random sampling, every 5th household was selected based on the sampling frame and target sample size, resulting in a total of

445 and 323 households in Teso South and Samia sub-counties, respectively. The respondents were interviewed using a semi-structured questionnaire programmed in ODK (open data kit) data collection software. Data on socioeconomic and demographic characteristics and climate change adaptation strategies were collected. Data cleaning was conducted using MS Excel. After data cleaning and the removal of cases with missing data and outliers due to incomplete questionnaires, non-responses, and data points that differ from other observations in the dataset, an analysis of data drawn from 723 households who engaged in crop production in the year 2021 was conducted using STATA 15.

2.3 Data analysis

2.3.1 Descriptive analysis

The collected data were analyzed using Excel 2021 and STATA version 15. Descriptive statistics, including frequencies, percentages, and graphs, were generated to illustrate the climate change adaptation strategies employed by farmers' households. A *t*-test was used to test the mean difference between the independent continuous variables used in the model between the adopters and the non-adopters, while a chi-square was used to test for the mean difference between the independent variables between the two groups.

2.3.2 Empirical framework

The study used principal component analysis (PCA) and multinomial logit regression (MNL) to assess the uptake of climate change adaptation strategies used by small-scale farmer households. First, PCA was used to group the adaptation strategies from 11 climate change adaptation strategies into four categories for the ease of analysis, as adapted from Aidoo et al. (2021). PCA is a commonly used statistical method for reducing dimensionality and extracting features, particularly useful in datasets containing a large number of variables. The study used PCA to transform the climate change adaptation strategies into a fresh set of uncorrelated variables called principal components. These components represent linear combinations of the original variables. The objective is to reduce the number of adaptation strategies and capture as much variability in the data as possible with a smaller number of principal components. However, it is important to test if the data is fit for the PCA analysis. The study employed the Kaiser-Meyer-Olkin (KMO) test, which requires the KMO value to be 0.5 or more (Hargreaves and Mani, 2015). The adaptation strategy with the highest factor loading in each category (the principal component) is selected to represent the other climate change adaptation strategies.

Secondly, multinomial logit regression was used to estimate the determinants of the uptake of climate change adaptation strategies. MNL is a statistical method used to predict the probability of multiple categories. The model estimates multiple equations simultaneously, each comparing one category to a reference category. The study used multinomial logistic regression (MNL) because the dependent variable is categorical and consists of five categories. These include four groups of farmers with different climate change adaptation strategies from the PCA analysis: cover crops, drought-resistant crops, irrigation, and crop diversity. The fifth category comprises farmers who do not use any climate change adaptation strategies, serving as the reference group. The explanatory variables used in the model include the size of the household, credit access, age of the household head, access to credit, group membership, frequency of climate change information, log-off farm income, and frequency of extension services. A multicollinearity test was also conducted between the independent variables before data analysis. The study employed VIF (variance inflation factors) to detect multicollinearity, and according to Gujarati (2003), a VIF value of more than 10 indicates the presence of multicollinearity. The representation of the multinomial logistic regression is provided below:

$$P\left(y = \frac{m}{x}\right) = \frac{\exp\left(\beta_m x_i\right)}{1 + \sum_{m=1}^{n} \exp\left(\beta\right),} \quad m = 1,\ 2 \ldots\ldots n \tag{2}$$

where m represents the climate change adaptation strategy, denoted by the random variables ranging from 1 to n, β is the estimated parameter, and x_i is the household characteristics or variables. After conducting the multinomial logistic regression, the marginal effect was calculated using Equation (2) to estimate the probability of choosing a given adaptation strategy with respect to the independent variable. The marginal effect was calculated (Equation 3) because the regression coefficient only indicates the direction of the effect, not the magnitude, and interpreting the coefficient will be misleading (Molla et al., 2023).

$$\frac{\partial P_{jm}}{\partial x_k} = P_m\left(\beta_{mk} - \sum_{J=1}^{J-1} P_j \beta_{mk}\right) \tag{3}$$

The study also estimated the determinants of the intensity of the use of climate change adaptation strategies by households using the ordered probit model because the dependent variable is ordered. The dependent variable used is the number of climate change adaptation strategies, which ranges from 0 to 5. The marginal effect of using more than two climate change adaptation strategies was summed up ($p = 2$ to $p = 5$) to represent the utilization of multiple climate change adaptation strategies (Bundi et al., 2020). The representation of the ordered probit model is as follows:

$$y^* = x_i\,\beta + \varepsilon_i \tag{4}$$

$y^*$is the latent variable and cannot be observed, but category responses can be observed, as shown in Equation (4) below:

$$y = \begin{cases} 0\ if\ y^* \le 0 \\ 1\ if\ 0 \le y^* \le \mu_1 \\ 2\ if\ \mu_2\ \le y^* \le \mu_2 \\ N\ if\ \mu_{N-1}\ < y^* \end{cases} \tag{5}$$

The independent variables are represented by x_i, β is the estimated parameter, μ is the threshold parameter, and ε is the error term as shown in Equation (5).

3 Results and discussions

3.1 Summary statistics of the independent variables used in the model

Table 1 shows the *t*-test and chi-square results of the means of variables used in the study for adopters, non-adopters, and overall households. These variables were selected based on previous studies (Amare and Simane, 2017; Marie et al., 2020; Aidoo et al., 2021; Atube et al., 2021; Kabir et al., 2021; Kogo et al., 2022; Jena et al., 2023). According to the results, 93% of the households had adopted climate change adaptation strategies, while 7% had not adopted any strategies. Adopters had an average age of 49, non-adopters had an average age of 46, and overall, the average age was around 48. This result concurs with Atsiaya et al. (2023), who reported that the mean age of the household head in Busia is 48. Approximately 50% of adopters had access to credit, compared to 52% of non-adopters.

The average number of visits by extension officers was about two for both adopters and non-adopters. This indicates no significant difference between the two groups in terms of extension visits. The average frequency of receiving climate change information was also approximately one for both groups, with no significant difference between them. The mean logs of off-farm income for adopters and non-adopters differed significantly at the 1% level. Adopters had a mean of 3.49, while non-adopters had a mean of 3.44. Financial resources like off-farm income tend to increase the adaptive capacity of farmers (Sorre et al., 2017).

The results also show that 21% of adopters and 12% of non-adopters had access to training, but the difference between the two groups was not significant. In terms of access to climate change information, 76.5% of adopters had access, compared to 64.8% of non-adopters. This shows that a higher percentage of farmers use adaptation strategies than non-users. Access to climate change information is linked to the uptake of adaptation strategies as farmers become aware of the weather patterns and response strategies (Marie et al., 2020). This difference was significant at the 1% level. Additionally, 72.5% of adopters were members of a farmer group or association, compared to 64.8% of non-adopters. This difference was significant at the 5% level. Farmer groups or associations help farmers share ideas, thus accelerating the uptake of climate change adaptation strategies (Adeagbo et al., 2023).

3.2 Climate change adaptation strategies, determinants of use, and intensity

This section presents the climate change adaptation strategies used by farmers, as well as the results of categorizing these strategies using principal component analysis. Additionally, the determinants of farmers' adoption of climate change adaptation strategies, as well as the factors influencing the intensity of use, are presented and discussed.

3.2.1 Climate change adaptation strategies used by farmers

Figure 2 shows the climate change adaptation strategies used by crop farmers in Busia County. The results show that half of the farmers used crop diversity, manure, and gardening technologies. Over 30% adopted timely planting, which consists of both late planting and early planting, intercropping, and cover crops (such as pumpkin crops). A total of 20% of the farmers adopted mulching, drought-resistant crops, and irrigation. Less than 20% of the farmers opted for improved seed varieties and short-season crops, while 7% did not use any adaptation strategies. Some studies (Asfaw et al., 2019; Gebru et al., 2020; Marie et al., 2020; Saddique et al., 2020; Getahun et al., 2021; Kabir et al., 2021; Mogaka et al., 2021; Kogo et al., 2022) have also documented some of these climate change adaptation strategies. However, gardening technologies emerged as a unique adaptation strategy used by the people of Busia. This includes the use of different gardening techniques, such as mandalas, keyholes, multistorey gardens, raised beds, and Zai pits, among others. This result shows a low uptake of different climate change adaptation strategies that may be important to address the climate issues in the county.

3.2.2 Categorization of climate change adaptation strategies

Table 2 shows the results of the principal component analysis with its factor loadings. The climate change adaptation strategies used by the crop farmers were grouped into four categories, including crop diversity, irrigation, cover crops, and drought-resistant crops. The adaptation strategy with the highest factor loading was selected from the adaptation strategies to represent each category of the four groups. The four components were picked because they had an eigenvalue of more than one and explained 57% of the variation in the data. To test if the data were fit for the PCA analysis, the KMO test was conducted, and the results showed an overall KMO of 0.55, which is more than the required minimum value (Hargreaves and Mani, 2015).

The adaptation strategy with the highest factor loading in each principal component was selected to represent the rest of the adaptation strategies under that category, as adopted by Ajak et al. (2018). Principal component 1 is represented by crop diversity, as it has the highest factor loading (0.498). The second principal component is represented by irrigation, which also has the highest factor loading of 0.448. The third principal component is represented by a cover crop with a loading of 0.545. The fourth principal component is represented by drought-resistant crops, with a loading of 0.571. The four adaptation strategy categories, along with the farmers who are not using any adaptation strategy, make up a total of five groups. These groups are used as the dependent variable in the MNL, with the farmers who are not using any strategy as the base category.

3.2.3 Determinants of farmers' climate change adaptation strategies

Table 3 shows the multinomial logistic results for the determinants of climate change adaptation strategies used by the farmers. On the overall fitness of the model, the likelihood ratio statistics LR chi-square (36) = 158 is highly significant ($P < 0.0000$). The model was also tested for multicollinearity using the variance inflation factor (VIF), and the VIF range for all variables is 1.04–1.28, indicating no problem of multicollinearity. The independence of the irrelevant assumption was also tested

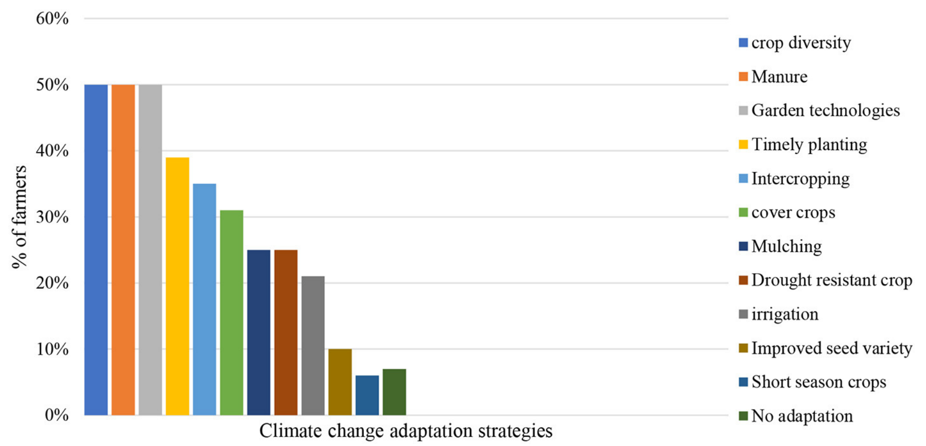

FIGURE 2
Climate change adaptation strategies used by crop farmers in Busia County (Source: Household survey data 2021).

TABLE 1 Summary statistics of the independent variables.

Variable	Adopters	Non-adopters	All farmers	2-tailed t-test
	$n = 669$	$n = 54$	$n = 723$	
Household size	6.46 (2.82)	5.96 (2.39)	6.43 (2.79)	1.27
Age	49.20 (14.23)	46.35 (16.62)	48.99 (14.43)	1.39
Log off-farm income	3.49(0.53)	3.44 (0.54)	3.48 (0.53)	1.97**
No extension visits	2.45 (1.71)	2.48 (1.80)	2.46 (1.72)	−0.12
Frequency of information	0.77(1.13)	0.74(1.18)	0.77(1.13)	0.172
	Percentage	Percentage	Percentage	X^2-values
Credit access (Yes = 1)	49.93	51.85	50.07	0.07
Training access (Yes = 1)	21.08	12.96	20.47	2.02
CC information access (Yes= 1)	76.53	64.81	75.66	3.72*
Group membership (Yes = 1)	72.50	57.41	71.37	5.57**
Extension access (Yes = 1)	35.19	34.98	34.99	0.001

*, **, *** denote significance at 10%, 5%, and 1% levels, respectively. Source: Household data survey 2021.

using the Hausman test, and the model fits since the test failed to reject the null hypothesis ($P > 0.05$) (Deressa et al., 2009).

According to the results, household size is significant and positively related to the use of drought-resistant crops as an adaptation strategy. This implies that an increase in household size by one increases the probability of a household choosing drought-resistant crops by 0.01%. This might be because larger households require more food to feed the family and may likely adopt adaptation strategies such as drought-resistant crops that could increase household food production and help them achieve their target (Amare and Simane, 2017), especially with unpredictable weather patterns. This concurs with other studies that have found a positive association between household size and climate change adaptation strategies (Belay et al., 2017; Diallo et al., 2020; Atube et al., 2021; Kogo et al., 2022). This highlights the need for tailoring climate change adaptation strategies to align with the characteristics of individual households.

Household size is also negatively related to the choice of cover crop. This shows that an increase in household size by one reduces the probability of a household choosing a cover crop by 0.99%. The negative relationship between household size and the uptake of cover crops was not expected. However, Taruvinga et al. (2016) also reported a negative association between family size and climate change adaptation strategies. Large household sizes sometimes have more dependents and thus spend more money on the dependents, hindering the uptake of climate adaptation strategies (Asfaw et al., 2019).

The results also show that access to credit is significant and positively related to the use of irrigation. This means that household heads who have access to credit are 7% more likely to use irrigation. This might be because irrigation technologies may require equipment that is beyond what small-holders can afford. Similarly, installation of this equipment is often technical and labor intensive, and it might require financial resources from the farmer (Amare and Simane, 2017; Jena et al., 2023). Thus, farmers who

TABLE 2 The principal component analysis result.

Adaptation strategies	Principle components				Categorization
	PC1	PC2	PC3	PC4	
Garden technologies	0.4590*				Crop diversity
Crop diversity	0.4983*				
Manure	0.3312*				
Mulching		0.4319*			Irrigation
Irrigation		0.4478*			
Timely planting			0.4046*		Cover crop
Cover crop			0.5547*		
Intercropping			−0.5839*		
Drought resistance crop				0.4571*	Drought resistance crop
Short season crops				−0.5036*	
Improved seed variety				0.2511*	
Eigenvalues	2.0433	1.5988	1.4056	1.1887	
Eigenvalues proportions	18.58	14.53	11.78	10.81	
Cumulative proportions	57				
Overall KMO	0.55				

The values in the principal components with * denote factor loadings.
PC, principal component; KMO, Kaiser-Meyer-Olkin test.

have access to credit may choose to invest in irrigation facilities that can improve their productivity and subsequently increase food production. This result is supported by Ojo and Baiyegunhi (2020), who also found a positive relationship between credit access and mixed cropping and improved variety as a climate change adaptation strategy.

Access to credit is also significant and negatively related to the use of cover crops as an adaptation strategy. This implies that household heads who have access to credit are less likely to use cover crops by 13%. The negative relationship between credit access and the cover crop may be associated with farmers using the credit to fund some other non-farm expenses or needs, thus hindering the uptake of adaptation strategies (Wekesa et al., 2018). The age of the household head is positively related to crop diversity. This implies that a one-year increase in age increases the probability of adopting crop diversity by 0.3%. An increase in age can be associated with experience and enable older farmers to better assess the best adaptation strategy to use. The age of the household head is also significant and negatively related to the use of drought-resistant crops. This shows that a year-long increase in age reduces the chance of using drought-resistant crops by 0.2%. The negative relationship might be a result of the young generation's ease in taking up new technologies faster than older farmers (Zhang et al., 2019; Baffour-Ata et al., 2023). The result is, however, consistent with Kogo et al. (2022), who reported a positive relationship between age and crop diversity as well as a negative relationship between age and the uptake of drought-tolerant varieties.

Training access is positively and significantly associated with the use of crop diversity, which implies that access to training increases the probability of a household practicing crop diversity by 9%. This might be because trained farmers are more likely to take up new technology or strategies that are important to them based on exposure to improving their yields or productivity in the ever-changing climate compared to their counterparts (Belay et al., 2017; Diallo et al., 2020). Training access was also significant and negatively associated with the use of cover crops, which means that access to training lessens the chance of using cover crops by 6%. The reason for a negative relationship was not expected. However, this might be a result of training not necessarily on cover crops but on other climate change adaptation strategies.

Group membership had a positive association with cover crops. This implies that belonging to any farmers' group or association increases the household's likelihood of using cover crops by 7%. Farmers' groups or associations act as a platform for knowledge sharing and transfer (Diro et al., 2022; Demem, 2023), and they are mostly used by different stakeholders for ease of disseminating information. The result corroborates Gebru et al. (2020), who found a positive and significant relationship between cooperative membership and different climate change adaptation strategies. The frequency of farmers receiving extension services was significant and positively associated with crop diversity as an adaptation strategy. This shows that a unit increase in contact with extension workers increases the probability of practicing crop diversity by 2%. This could be because frequent contact with the extension worker increases farmers' awareness of different technologies as well as adaptation strategies that could help them improve their productivity and livelihood in the ever-changing climate. The results corroborate Demem (2023), who found a positive relationship between the number of extension visits and the uptake of different climate change adaptation strategies.

The frequency with which farmers receive climate change information had a positive and significant impact on the use of crop diversity, irrigation, and cover crops, suggesting that a unit increase in the number of times a farmer receives climate change information increases the probability of using crop diversity, irrigation, and cover crops by 4%, 3%, and 3%, respectively. The more frequently farmers receive climate-related information, the greater their awareness and influence on the adoption of different adaptation strategies, as reported by Atube et al. (2021). This implies that farmers are better prepared and are able to plan their adaptation strategies in advance based on the information provided and make informed decisions (Kumar et al., 2023). This result is supported by Mabe et al. (2014), who found a positive association between weather information and the adoption of tree planting as an adaptation strategy in Northern Ghana. The frequency of farmers receiving climate change information was also negative and significantly associated with the uptake of drought-resistant crops. This implies that a unit increase in the number of times the farmer receives climate change information reduces the chances of using the drought-resistant crop by 10%. This was contrary to the expectations. However, the negative association with drought-resistant crops may be a result of the information received not necessarily being related to drought-resistant crops.

Off-farm income had a positive relationship with the uptake of crop diversity. This could be because crop diversity may require additional funds to purchase different inputs, including improved seeds, which can be expensive (Molla et al., 2023). Thus, those with additional sources of income may have the resources needed to invest in crop diversification, unlike their counterparts, who solely depend on farm income. This finding is supported by Kogo et al. (2022), who found a positive relationship between income and the use of soil conservation as an adaptation strategy. Conversely, off-farm income also had a significant and negative relationship with the uptake of cover crops and drought-resistant crops. The negative relationship might be due to farmers with non-farm income shifting their focus to off-farm activities rather than adopting climate change adaptation strategies (Ojo and Baiyegunhi, 2020).

3.2.4 Determinants of farmers' climate change adaptation intensity

Table 4 presents the results of the ordered probit model. According to the results, credit access, extension services, off-farm income, training access, group membership, and climate change information were associated with the use of multiple climate change adaptation strategies.

The results show that access to credit is positively and significantly related to the uptake of multiple climate change adaptation strategies. This implies that access to credit increases the probability of adopting multiple climate change adaptation strategies by 17.8%. Access to credit provides enough financial support and financial resources to farmers to adopt climate change adaptation strategies (Atube et al., 2021). Financial resources are one of the challenges faced by farmers and act as a barrier to the uptake of different adaptation strategies (Moniruzzaman et al., 2023) because some of the adaptation strategies are expensive, such as the installation of irrigation systems and crop diversification. This result concurs with Teklewold et al. (2019), who reported that the inability to access credit limits the adoption of multiple climate-smart strategies in Ethiopia.

Off-farm income also had a positive and significant relationship and increased the probability of the farmers using multiple adaptation strategies by 9.3%. Off-farm income provides additional monetary resources to help the farmers uptake multiple climate change adaptation strategies that will enable them to cope with the negative effects of climate change. These results are supported by Bundi et al. (2020), who reported a positive relationship between off-farm income and uptake of multiple pre-harvesting practices among mango farmers in Kenya.

Access to training is significantly and negatively associated with the use of multiple climate change adaptation strategies. This implies that access to training reduces the probability of using multiple climate change adaptation strategies by 5.42%. This result is contrary to the expectations, but Kpadonou et al. (2017) reported that attending training does not necessarily lead to an increased adoption rate. This may be due to trainings that focus on specific adaptation strategies, thus making farmers specialize in a given strategy rather than adapting diverse strategies. The results may also be contributed by the misalignment of the farmers' needs with the training offered; strategies being emphasized in training may not be directly relevant to farmers' needs in their local context, thus limiting their uptake of a wider range of adaptation strategies.

According to the results, group membership is significant and negatively related to the uptake of multiple climate change adaptation strategies, suggesting that a farmer's participation in a group, cooperative, or even association reduces the probability of adopting multiple climate change adaptation strategies by 22.6%. This finding aligns with Adeagbo et al. (2023), who found a negative relationship between membership and the level of adoption of climate change adaptation strategies among small-holder maize farmers in southwest Nigeria.

The results also show that access to extension services is negatively and significantly associated with the uptake of multiple climate change adaptation strategies. This implies that access to extension services from the government or other service providers reduces the probability of households using multiple adaptation strategies by 0.6%. This finding was unexpected as extension services are expected to create awareness and provide knowledge and information regarding different adaptation strategies, as reported in previous studies (Amare and Simane, 2017; Baffour-Ata et al., 2023; Demem, 2023). However, the uptake of multiple climate change adaptation strategies may require a lot of financial investment from farmers, and knowledge alone is not enough. Rather, it needs other factors to supplement it, such as financial aspects, thus creating a negative relationship.

Access to climate change information is negatively and significantly associated with the uptake of multiple climate change adaptation strategies. This means that access to climate change information increases the probability of using multiple climate change adaptation strategies by 9.3%. This outcome was unexpected, as access to climate change information is supposed to provide farmers with knowledge about expected weather patterns and changes, allowing them to prepare and implement various adaptation strategies (Adeagbo et al., 2023).

TABLE 3 Factors affecting the adoption of climate change adaptation strategies (multinomial logit regression).

Variable	Crop diversity *dy/dx*	Irrigation *dy/dx*	Cover crops *dy/dx*	Drought resistance crop *dy/dx*
Household size	0.0043 (0.007)	0.0009 (0.006)	−0.0111* (0.006)	0.0099* (0.005)
Credit access	0.0306 (0.041)	0.0740** (0.036)	−0.1288*** (0.034)	0.0561 (0.035)
Age	0.0030** (0.001)	−0.0003 (0.001)	−0.0007 (0.001)	−0.0023** (0.001)
Training access	0.0852* (0.048)	0.0064 (0.041)	−0.0640* (0.034)	−0.0583 (0.039)
Membership access	−0.0060 (0.045)	−0.1066*** (0.040)	0.0695* (0.037)	−0.0116 (0.036)
extension	0.0186* (0.011)	−0.0462*** (0.009)	−0.0362*** (0.010)	−0.0306*** (0.009)
Information	0.0364** (0.017)	0.0280* (0.015)	0.0256* (0.04)	−0.1008*** (0.020)
Log income (off-farm)	0.0908*** (0.019)	0.0110 (0.017)	−0.0434*** (0.016)	−0.0403** (0.016)
No of observation	723			
Base category	No adaptation			
LR chi-square (36) Prob > chi^2	1,580.0000			
Log likelihood	−1,023.3			
Pseudo *r*	0.1			

The values denote the marginal effect (dy/dx) with standard errors in parentheses. *, **, *** denote significance at the 10%, 5%, and 1% levels, respectively.
Source: Household survey data for 2021.

TABLE 4 Factors affecting the use of multiple climate change adaptation strategies adopted (Ordered probit regression).

Variable	Coefficient	SE	Marginal effect					
			Prob ($Y = 0\|X$) *dy/dx*	Prob ($Y = 1\|X$) *dy/dx*	Prob ($Y = 2\|X$) *dy/dx*	Prob ($Y = 3\|X$) *dy/dx*	Prob ($Y = 4\|X$) *dy/dx*	Prob ($Y = 5\|X$) *dy/dx*
HH size	0.0202	0.013	−0.0025	−0.0034	−0.0022	0.0015	0.0032	0.0033
Credit	0.6124***	0.087	−0.0759***	−0.1022***	−0.0654***	0.0463***	0.0967***	0.1004***
Training	−0.3457***	0.10	0.0428***	0.0577***	0.0369***	−0.0261***	−0.0546***	−0.0567***
Membership	−0.2325**	0.093	0.0288**	0.0388**	0.0248**	−0.1758**	−0.0367**	−0.0381**
Extension	0.1667**	0.082	−0.0206**	−0.0278**	−0.0178**	0.0126**	0.0263**	0.0273**
Log income (off-farm)	0.3188***	0.077	−0.0395***	−0.0532***	−0.0341***	0.0241***	0.0503***	0.0523***
Information	−0.3209***	0.094	0.0397***	0.0535***	0.0343***	−0.0243***	−0.0507***	−0.0526***
Sample size	723							
Prob > chi^2	0.000							
Log likelihood	−1,238.51							

*, **, *** denote significance at 10%, 5%, and 1% levels, respectively. dy/dx is the marginal effect.
Source: Household survey data 2021.

4 Conclusions and policy recommendations

The study shows that crop farmers in Busia adopted different climate change adaptation strategies for sustainability and to build resilience against the negative impact of climate change. The adaptation strategies adopted include crop diversity, manure application, gardening technologies, timely planting, intercropping, irrigation, mulching, use of drought-resistance crops, cover crops, improved seed varieties, and short-season crops. It is evident from these results that there is a low uptake of most climate change adaptation strategies, yet they are important in building resilience among crop farmers. The use of different climate change adaptation strategies is also the county's strategy and priority to reduce the impact of climate change and improve household livelihoods. Thus, this study offers data that will help design interventions and programs that incorporate climate adaptation strategies tailored to the diverse challenges crop farmers face due to climate change.

Various factors such as age, household size, access to credit, training access, off-farm income, group membership, frequency of receiving climate change information, and extension services have contributed to the uptake of different adaptation strategies among farmers in Busia. Off-farm income and access to credit contributed to the uptake of multiple climate change adaptation strategies. Notably, certain adaptation strategies, such as the use of cover crops, do not rely on credit and thus present a viable option in a resource-constrained environment, given their potential to improve productivity and household food and nutrition security. However, strategies such as irrigation need financial resources to be implemented. This shows the importance of information and awareness in driving the adoption of various adaptation strategies while also highlighting the complementary role of financial resources, especially for the uptake of multiple strategies. Therefore, the study recommends policies and interventions that integrate knowledge-oriented approaches such as extension services, training, climate change education, and group participation, as well as financial mechanisms like income generation and credit access. These combined efforts will help farmers adopt diverse and multiple adaptation strategies for sustainable crop production. This highlights the need for targeted support and capacity-building programs that align with farmers' needs and challenges. These interventions can also be coupled with credit access in some scenarios to assist farmers in overcoming the technical and operational challenges associated with limited resources. The study suggests the mainstreaming of the knowledge aspect in extension both by the government and other extension service providers to capacity build farmers on the best climate change adaptation strategies and climate change information to help them adapt to relevant strategies based on their climate change challenges and needs; this will help in building farmers resilience toward climate change, thus improving their livelihood. The study also recommends that policymakers and financial institutions collaborate and facilitate accessible and affordable credit mechanisms to support small-holder farmers in acquiring different climate change adaptation strategies based on their challenges. The government and other stakeholders in the field may also develop programs that promote a balance between resource-intensive strategies and sustainable agricultural practices that are less resource intensive to encourage a wider range of climate change adaptation strategies among the farmers for improved productivity and food security.

This study also provides detailed insights into various climate change adaptation strategies that can be used by crop farmers in areas similar to those studies, as well as by policymakers, to design policies and interventions for sustainable crop production in an ever-changing climate. The study recommends that future research should systematically examine the specific content and delivery mechanisms of climate change adaptation training programs for farmers. Additionally, there is also a call for future studies to explore credit access in relation to climate change adaptation strategies, including the cost of such credit and the ability of farmers to repay. By employing panel data analysis, researchers could study how well the alignment between training content and farmers' needs affects the long-term adoption of adaptation strategies and their subsequent impact on household food security and other livelihood outcomes.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

AMN: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing, Data curation. JM: Conceptualization, Methodology, Writing – review & editing, Supervision. RM: Conceptualization, Methodology, Writing – review & editing, Supervision. CC: Conceptualization, Methodology, Writing – review & editing, Supervision.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This work was supported by German Academic Exchange Service (DAAD) and African Economic Research Consortium (AERC) under a full PhD scholarship at the University of Nairobi Kenya.

Acknowledgments

The authors are grateful to the German Academic Exchange Service (DAAD) and the African Economic Research Consortium (AERC) for funding this research and to the farmers of Busia County for giving their consent and agreeing to be part of the survey.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Adeagbo, O. A., Bamire, A. S., Akinola, A. A., Adeagbo, A. D., Oluwole, T. S., Ojedokun, O. A., et al. (2023). The level of adoption of multiple climate change adaptation strategies: evidence from small-holder maize farmers in Southwest Nigeria. *Sci. Afr.* 22:e01971. doi: 10.1016/j.sciaf.2023.e01971

Adhikari, U., Nejadhashemi, A. P., and Woznicki, S. A. (2015). Climate change and eastern Africa: a review of impact on major crops. *Food Energy Secur.* 4, 110–132. doi: 10.1002/fes3.61

Aidoo, D. C., Boateng, S. D., Freeman, C. K., and Anaglo, J. N. (2021). The effect of small-holder maize farmers' perceptions of climate change on their adaptation strategies: the case of two agroecological zones in Ghana. *Heliyon* 7:e08307. doi: 10.1016/j.heliyon.2021.e08307

Ajak, B. J., Kyazze, F. B., and Mukwaya, P. I. (2018). Choice of adaptation strategies to climate variability among small-holder farmers in the maize based cropping system in Namutumba District, Uganda. *AJCC* 07, 431–451. doi: 10.4236/ajcc.2018.73026

Amare, A., and Simane, B. (2017). Determinants of small-holder farmers' decision to adopt adaptation options to climate change and variability in the Muger Sub basin of the Upper Blue Nile basin of Ethiopia. *Agric. Food Secur.* 6:64. doi: 10.1186/s40066-017-0144-2

Asfaw, A., Simane, B., Bantider, A., and Hassen, A. (2019). Determinants in the adoption of climate change adaptation strategies: evidence from rainfed-dependent small-holder farmers in north-central Ethiopia (Woleka sub-basin). *Environ. Dev. Sustain.* 21, 2535–2565. doi: 10.1007/s10668-018-0150-y

Atsiaya, G. O., Gido, E. O., and Waluse Sibiko, K. (2023). Uptake of climate-smart agricultural practices among small-holder sorghum farmers in Busia County, Kenya. *Cogent Food Agric.* 9:2204019. doi: 10.1080/23311932.2023.2204019

Atube, F., Malinga, G. M., Nyeko, M., Okello, D. M., Alarakol, S. P., Okello-Uma, I., et al. (2021). Determinants of small-holder farmers' adaptation strategies to the effects of climate change: evidence from northern Uganda. *Agric. Food Secur.* 10:6. doi: 10.1186/s40066-020-00279-1

Baffour-Ata, F., Awugyi, M., Ofori, N. S., Hayfron, E. N., Amekudzi, C. E., Ghansah, A., et al. (2023). Determinants of yam farmers' adaptation practices to climate variability in the Ejura Sekyedumase municipality, Ghana. *Heliyon* 9:e14090. doi: 10.1016/j.heliyon.2023.e14090

Bartlett, J. E., Kotrlik, J. W., and Higgins, C. C. (2001). Organizational research: determining appropriate sample size in survey research. *Inform. Technol. Learn. Perform. J.* 19, 43–50. doi: 10.5032/jae.2002.03001

Belay, A., Recha, J. W., Woldeamanuel, T., and Morton, J. F. (2017). Small-holder farmers' adaptation to climate change and determinants of their adaptation decisions in the Central Rift Valley of Ethiopia. *Agric. Food Secur.* 6:24. doi: 10.1186/s40066-017-0100-1

Bundi, A., Mburu, J., Mbogoh, S. G., and Ambuko, J. L. (2020). Factors influencing the adoption of pre-harvest practices among mango farmers in Embu and Machakos counties, Kenya. *IJPTI* 7:56. doi: 10.1504/IJPTI.2020.108744

Campbell, B. M., Wollenberg, E., Vermeulen, S. J., Girvetz, E., Loboguerrero, A. M., Ramirez-Villegas, J., et al. (2016). Reducing risks to food security from climate change. *Glob. Food Secur.* 11, 34–43. doi: 10.1016/j.gfs.2016.06.002

Chen, S., and Gong, B. (2021). Response and adaptation of agriculture to climate change: evidence from China. *J. Dev. Econ.* 148:102557. doi: 10.1016/j.jdeveco.2020.102557

Cochran, W. G. (1977). *Sampling Techniques*, 3rd Edn. Wiley series in probability and mathematical statistics. New York, NY: Wiley.

Demem, M. S. (2023). Impact and adaptation of climate variability and change on small-holders and agriculture in Ethiopia: a review. *Heliyon* 9:e18972. doi: 10.1016/j.heliyon.2023.e18972

Deressa, T. T., Hassan, R. M., Ringler, C., Alemu, T., and Yesuf, M. (2009). Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Glob. Environ. Change* 19, 248–255. doi: 10.1016/j.gloenvcha.2009.01.002

Diallo, A., Donkor, E., and Owusu, V. (2020). Climate change adaptation strategies, productivity and sustainable food security in southern Mali. *Clim. Change* 159, 309–327. doi: 10.1007/s10584-020-02684-8

Diro, S., Tesfaye, A., and Erko, B. (2022). Determinants of adoption of climate-smart agricultural technologies and practices in the coffee-based farming system of Ethiopia. *Agric. Food Secur.* 11:42. doi: 10.1186/s40066-022-00385-2

FAO (2015). Climate change and food security: risks and responses. Rome: FAO

Food and Agriculture Organization (2023). *The State of Food Security and Nutrition in the World* 2023. Rome: FAO; IFAD; UNICEF; WFP; WHO. doi: 10.4060/cc3017en

Francis, M.-T., Julius, M., Abdil, K. E., and Edwin, K. (2017). Determinants of adoption of multiple climate change adaptation strategies in Southern Malawi: an ordered probit analysis. *J. Dev. Agric. Econ.* 9, 1–7. doi: 10.5897/JDAE2016.0753

Gebru, G. W., Ichoku, H. E., and Phil-Eze, P. O. (2020). Determinants of small-holder farmers' adoption of adaptation strategies to climate change in Eastern Tigray National Regional State of Ethiopia. *Heliyon* 6:e04356. doi: 10.1016/j.heliyon.2020.e04356

Getahun, A. B., Ayal, D. Y., Ture, K., and Zeleke, T. T. (2021). Determinants of climate variability adaptation strategies: a case of Itang Special District, Gambella Region, Ethiopia. *Clim. Serv.* 23:100245. doi: 10.1016/j.cliser.2021.100245

GOK (2018a). *Busia County-County Intergrated Development Plan (CIDP) 2018-2022*. Nairobi, Kenya.

GOK (2018b). *National Climate Change Action Plan (Kenya): 2018-2022*. Nairobi: Ministry of Environment and Forestry I. Nairobi, Kenya.

GOK (2023). *Busia County-County Intergrated Development Plan (CIDP) 2023-2027*. Nairobi, Kenya.

Government of Kenya (2017). *Kenya Climate Smart Agriculture Strategy-2017-2026*. Nairobi, Kenya. 1-137. Available online at: https://repository.kippra.or.ke/handle/123456789/2064

Gujarati, D. N. (2003). *Student solutions manual for use with "Basic econometrics,"* 4th Edn. McGraw-Hill higher education. Boston, MA: McGraw Hill.

Hargreaves, C. A., and Mani, C. K. (2015). The selection of winning stocks using principal component analysis. *Am. J. Market. Res.* 1, 183–188.

Irene, O., Erick, M., Charles, M., Jane, G., Tessy, A., Lilian, M., et al. (2022). Household characteristics influencing management of indigenous chicken: a case study of Machakos and Busia Counties in Kenya. *J. Vet. Med. Anim. Health* 14, 91–101. doi: 10.5897/JVMAH2022.1014

Jena, P. R., Tanti, P. C., and Maharjan, K. L. (2023). Determinants of adoption of climate resilient practices and their impact on yield and household income. *J. f Agric.Food Res.* 14:100659. doi: 10.1016/j.jafr.2023.100659

Kabir, A., Amin, M. N., Roy, K., and Hossain, M. S. (2021). Determinants of climate change adaptation strategies in the coastal zone of Bangladesh: implications for adaptation to climate change in developing countries. *Mitig. Adapt. Strateg. Glob. Change* 26:30. doi: 10.1007/s11027-021-09968-z

Kogo, B. K., Kumar, L., Koech, R., and Hasan, M. K. (2022). Response to climate change in a rain-fed crop production system: insights from maize farmers of western Kenya. *Mitig Adapt Strateg. Glob. Change* 27:50. doi: 10.1007/s11027-022-10023-8

Kpadonou, R. A. B., Owiyo, T., Barbier, B., Denton, F., Rutabingwa, F., Kiema, A., et al. (2017). Advancing climate-smart-agriculture in developing drylands: Joint analysis of the adoption of multiple on-farm soil and water conservation technologies in West African Sahel. *Land Use Policy* 61, 196–207. doi: 10.1016/j.landusepol.2016.10.050

Kumar, K. N. R., Reddy, M. J. M., Reddy, K. V., Paramesha, V., Balasubramanian, M., Kumar, T. K., et al. (2023). Determinants of climate change adaptation strategies in South India: empirical evidence. *Front. Sustain. Food Syst.* 7:1010527. doi: 10.3389/fsufs.2023.1010527

Lobell, D. B. (2014). Climate change adaptation in crop production: beware of illusions. *Glob. Food Secur.* 3, 72–76. doi: 10.1016/j.gfs.2014.05.002

Mabe, F. N., Sienso, G., and Donkoh, S. A. (2014). Determinants of choice of climate change adaptation strategies in Northern Ghana. *RAE* 6:75. doi: 10.5296/rae.v6i4.6121

Marie, M., Yirga, F., Haile, M., and Tquabo, F. (2020). Farmers' choices and factors affecting adoption of climate change adaptation strategies: evidence from northwestern Ethiopia. *Heliyon* 6:e03867. doi: 10.1016/j.heliyon.2020.e03867

McKinley, J. D., LaFrance, J. T., and Pede, V. O. (2021). Climate change adaptation strategies vary with climatic stress: evidence from three regions of Vietnam. *Front. Sustain. Food Syst.* 5:762650. doi: 10.3389/fsufs.2021.762650

MoALF (2014). *Climate Risk Profile for Busia. Kenya County Climate Risk Profile Series*. Nairobi: The Kenya Ministry of Agriculture, Livestock and Fisheries (MoALF).

Mogaka, B. O., Bett, H. K., Ng'ang'a, and S. K. (2021). Socioeconomic factors influencing the choice of climate-smart soil practices among farmers in western Kenya. *J. Agric. Food Res.* 5:100168. doi: 10.1016/j.jafr.2021.100168

Mohammed, A., and Misganaw, A. (2022). Modeling future climate change impacts on sorghum (Sorghum bicolor) production with best management options in Amhara Region, Ethiopia. *CABI Agric. Biosci.* 3:22. doi: 10.1186/s43170-022-00092-9

Molla, E., Melka, Y., and Desta, G. (2023). Determinants of farmers' adaptation strategies to climate change impacts in northwestern Ethiopia. *Heliyon* 9:e18514. doi: 10.1016/j.heliyon.2023.e18514

Molotoks, A., Smith, P., and Dawson, T. P. (2021). Impacts of land use, population, and climate change on global food security. *Food Energy Secur.* 10:e261. doi: 10.1002/fes3.261

Moniruzzaman, Haque, S., Haque, A. K. E., Rahman, M. S., Islam, A. H. M. S., and Salam, M. A. (2023). Farmer's perception, observed trend and adaptation measures to climate change: evidence from wheat farmers in Bangladesh. *J. Agric. Food Res.* 14:100873. doi: 10.1016/j.jafr.2023.100873

Mulungu, K., Tembo, G., Bett, H., and Ngoma, H. (2021). Climate change and crop yields in Zambia: historical effects and future projections. *Environ. Dev. Sustain.* 23, 11859–11880. doi: 10.1007/s10668-020-01146-6

Nelson, G. C., Rosegrant, M., Koo, J., Robertson, R., Sulser, T., Zhu, T., et al. (2009). *Climate change: Impact on agriculture and costs of adaptation*. Washington, DC: International Food Policy Research Institute.

Niang, I., Ruppel, O. C., Abdrabo, M., Ama, E., Lennard, C., Adelekan, I. O., et al. (2014). "Chapter 22 Africa," in *Climate Change 2014: Impacts, Adaptation, and*

Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, eds. V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, et al. (Cambridge: Cambridge University Press), 688.

Niyibigira, T., Mohammed, W., Tana, T., Lemma Tefera, T., and Rukundo, P. (2024). Sorghum farmers' perceptions of climate change, its effects, temperature and precipitation trends, and determinants of adaptation strategies in the central plateau zone of Rwanda. *Cogent. Food Agric.* 10:2334999. doi: 10.1080/23311932.2024.2334999

Ochieng, J., Kirimi, L., and Mathenge, M. (2016). Effects of climate variability and change on agricultural production: the case of small scale farmers in Kenya. *NJAS Wagen. J. Life Sci.* 77, 71–78. doi: 10.1016/j.njas.2016.03.005

Ojo, T. O., and Baiyegunhi, L. J. S. (2020). Determinants of climate change adaptation strategies and its impact on the net farm income of rice farmers in southwest Nigeria. *Land Use Policy* 95:103946. doi: 10.1016/j.landusepol.2019.04.007

Reidsma, P., Ewert, F., Lansink, A. O., and Leemans, R. (2010). Adaptation to climate change and climate variability in European agriculture: the importance of farm level responses. *Eur. J. Agron.* 32, 91–102. doi: 10.1016/j.eja.2009.06.003

Saddique, Q., Cai, H., Xu, J., Ajaz, A., He, J., Yu, Q., et al. (2020). Analyzing adaptation strategies for maize production under future climate change in Guanzhong Plain, China. *Mitig. Adapt. Strateg. Glob. Change* 25, 1523–1543. doi: 10.1007/s11027-020-09935-0

Singh, A., and Purohit, B. M. (2014). Public health impacts of global warming and climate change. *Peace Rev.* 26, 112–120. doi: 10.1080/10402659.2014.876326

Singh, A. S., and Masuku, M. B. (2014). Sampling techniques & determination of sample size in applied statistics research: an overview. *Int. J. Econ. Commerce Manage.* 2, 1–22.

Sorre, A. M., Kurgat, A., Musebe, R., and Sorre, B. (2017). Adaptive capacity to climate change among smallholder farmers' in Busia County, Kenya. *J. Agric. Vet. Sci.* 10, 40–48.

Taruvinga, A., Visser, M., and Zhou, L. (2016). Determinants of rural farmers' adoption of climate change adaptation strategies: evidence from the amathole district municipality, Eastern Cape Province, South Africa. *IJESD* 7, 687–692. doi: 10.18178/ijesd.2016.7.9.863

Teklewold, H., Mekonnen, A., and Kohlin, G. (2019). Climate change adaptation: a study of multiple climate-smart practices in the Nile Basin of Ethiopia. *Clim. Dev.* 11, 180–192. doi: 10.1080/17565529.2018.1442801

Wekesa, B. M., Ayuya, O. I., and Lagat, J. K. (2018). Effect of climate-smart agricultural practices on household food security in small-holder production systems: micro-level evidence from Kenya. *Agric. Food Secur.* 7:80. doi: 10.1186/s40066-018-0230-0

World Bank (2020). *Kenya - Inclusive Growth and Fiscal Management Development Policy Financing Project*. Washington, DC: World Bank Group.

Zhang, B., Fu, Z., Wang, J., and Zhang, L. (2019). Farmers' adoption of water-saving irrigation technology alleviates water scarcity in metropolis suburbs: a case study of Beijing, China. *Agric. Water Manag.* 212, 349–357. doi: 10.1016/j.agwat.2018.09.021