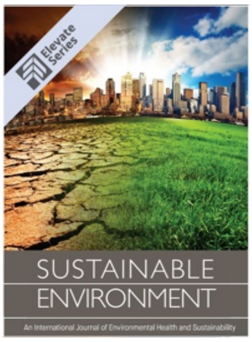

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Farm level adaptation strategies to climate change among coffee farmers in Northern Uganda: A multivariate probit approach

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ABSTRACT

Climate change continues to pose a significant threat to human and animal lives. This is evident in the decline in agricultural productivity, which is attributed to drought and extreme temperatures, resulting in increased food prices across the globe. The adoption of climate change adaptation strategies can reduce the negative effects of climate change. However, there are limited studies on the types of adaptation strategies adopted by coffee farmers and their determinants in Northern Uganda. This study assessed the types of farmers' adaptive strategies as well as the determinants of farmers' adaptation strategies to the effects of climate change in Northern Uganda. Data were collected from 202 smallholder coffee farmers using a multistage sampling by administering a well-developed semi-structured questionnaire. Multivariate Probit model was used for the regression analysis. The results showed that agroforestry, cover crops, mulching and crop rotation were the most adopted strategies, while inorganic fertilizer and organic fertilizer were adopted by a few farmers. The results of the econometric analysis showed that socio-economic factors such as gender, age, education, farming scale, household size, farming experience, extension visits, group membership, access to climate change adaptation training, market linkages and market distance had significant effects on the adoption of climate change adaptation strategies among the farmers. Farmers need to be trained on climate change adaptation strategies while also supporting them through farm inputs. Group membership and participation should be promoted among farmers. Subsidizing farm inputs such as inorganic fertilizers can also result in a high adoption rate.

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Agricultural resilience; smallholder decision-making; agricultural productivity; climate variability; adaptive capacity

Introduction

Globally, agriculture has a huge potential to reduce the rising level of food insecurity (FAO, 2009). The agricultural production gap has resulted in food insecurity among many citizens, especially in sub-Saharan Africa (Ongoma et al., 2025). According to the Food Security Report published by the WFP (2024), 54 million people are food insecure in East Africa, with Ethiopia, Sudan and South Sudan topping the list. Moreover, South and Central Africa have also reported rising levels of food insecurity among citizens (AGRA, 2024). The rising levels of food crisis have resulted in a decline in life expectancy among citizens of Sub-Saharan Africa (Beyene, 2023). Poverty, malnutrition and illness are evident among food-insecure households (UNDP, 2014). Citizens of such vulnerable economies remain hopeless, with the majority depending on food aid from Western countries (Asiama & Nell, 2024).

Many organizations have recommended intensive investment in agricultural production since it has the potential to save sub-Saharan African nations from food insecurity (Ayuko et al., 2024; Diao et al., 2010). Crops, livestock, fisheries and all agricultural-related activities play more than just roles in food provision. These sub-sectors ensure that the primary economic agents have adequate income to meet their household needs, thereby improving their living standards (Diao et al., 2010). Moreover, the role of agriculture is evident in its contribution to the Gross Domestic Product (OECD & FAO, 2016). However, climate change

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poses a significant threat to agricultural productivity globally (Muthoka et al., 2024). The impacts of climate change affect not only national food production but also international food prices (Ouko et al., 2024; World Bank, 2015). Past studies have shown that agricultural output has been steadily declining because of harsh weather conditions such as high temperatures (WHO, 2020).

Moreover, drought has been evident in many parts of Sub-Sahara Africa (SSA), which affects not only crops but also livestock production (FAO, 2021). Excess rain has also resulted in the loss of topsoil nutrients as well as green vegetation, posing a great threat to future food production in Sub-Saharan Africa as a result of infertile and weathered soils (Wekesa et al., 2018). Moreover, pests and diseases such as fall and armyworms have emerged as a result of too little rain, which creates favorable laying conditions not only for the fall armyworm but also for other pests and diseases (Murray et al., 2019). This also contributes to the low quality and quantity of cereal crops, such as maize, which is a staple food for the majority of Sub-Saharan African households (Muthoka et al., 2024). Yield variability has been reported across many regions of SSA, leading to irrational decision-making regarding the type of cropping system among farmers (FAO, 2016). Moreover, future projections suggest that stable food crops, such as maize, will experience losses of up to $200 million annually (World Bank, 2015). Similarly, the productivity of crops such as sorghum and wheat is expected to decline by 18.1% and 13.2%, respectively (Kassaye et al., 2021). This will increase food prices, which are expected to increase by 75% to 90% by 2055 (World Bank, 2022). In Uganda, climate change has reduced the productivity of major food and cash crops such as coffee (Atube et al., 2021).

Climate change adaptation and mitigation strategies have emerged as viable solutions to reduce the adverse effects of climate change on agriculture (Saadu et al., 2024). Farmers need to practice and embrace mitigation and adaptation strategies to bridge the productivity gap. Reports emanating from studies on the impacts of climate-smart agricultural strategies suggest that adaptation strategies have positive impacts on crop productivity. For example, Saadu et al. (2024) highlighted that climate change adaptation strategies increase farm income and crop yield and eventually ensure household food security in Nigeria. Agbenyo et al. (2022) found that farmers who embrace climate change adaptation strategies are higher-income earners than their counterparts who practice traditional farming. Wekesa et al. (2018) explained that climate change adaptation strategies can be used to reduce the looming food crisis in Kenya. Reports published by the World Bank (2015) recommended the intensive use of climate change adaptation strategies to help farmers overcome poverty, food insecurity and malnutrition. Although there are countless benefits of adaptation strategies, findings from recent studies have shown that their adoption rate has not reached the optimal level (Kassa & Abdi, 2022; Mthethwa et al., 2022; Ojo et al., 2023; Saadu et al., 2024; Sanogo et al., 2023).

To improve the rate of adoption of climate change adaptation strategies among farmers, this study examined the determinants of farmers' adaptation strategies to the effects of climate change in Uganda using primary data among coffee farmers. At the global level, available studies on the determinants of adaptation strategies to climate change have produced varying and conflicting influence of socio-economic factors on farmers' adaptation strategies to climate change (Abdullahi et al., 2021; Kassa & Abdi, 2022; Kirungi et al., 2023; Mthethwa et al., 2022; Negera et al., 2022; Sanogo et al., 2023; Wekesa et al., 2018). These varied results are evident in socio-economic, institutional, market, farm and farmer-related factors as a result of the variations in the methodological approaches adopted by the authors.

Moreover, some studies have generalized farmers while others have considered food crop farmers while others have been conducted among cash crop farmers. For example, Atube et al. (2021) assessed the drivers of the adoption of CCASs among farmers in Northern Uganda. However, their study generalized farmers rather than focusing on significant crops of high value to the economy such as coffee. In Nigeria, Kalu and Mbanasor (2020) researched on farmers' adoption of climate smart practices among root crops farmers. Their work put more emphasis on root crops only. In addition, Bedeke et al. (2019) study on farmers' adaptation strategies to climate change and focused on maize in Nigeria. Furthermore, Omodara et al. (2023) analyzed how cassava farmers adapt to climate variability in Nigeria. Sanogo et al. (2023) studied the covariates affecting rice farmers' adoption of climate smart practice in Mali.

Despite the significant contribution of coffee to household food security through the high income earned and spent to purchase food (Bacsi et al., 2022), there is limited work done on how farmers in the coffee farming system adapt to the adverse effects of climate variability and the drivers of adoption of climate change adaptation strategies, as many studies have been done on other crops. Thus, the objective of this study is to assess the climate change adaptation strategies employed by coffee farmers in Northern Uganda and their socio-economic determinants. Therefore, this study contributes to the existing knowledge on the determinants of adaptation strategies to the adverse effects of climate change among coffee farmers in the Nwoya and Oyam districts of Northern Uganda, where coffee farming is highly promoted and practiced to improve the living standards of farmers. Nwoya and Oyam boast favorable climates and fertile soils for coffee production, thus, coffee farming is highly promoted in these two regions of Uganda. The findings serve as recommendations to the public, government, policymakers, smallholder farmers and non-governmental agricultural organizations that work tirelessly to improve food production through the adoption of CCASs.

Literature review

Climate change continues to have significant negative effects on agricultural production globally (Emediegwu et al., 2022). To inform policy makers on the policies to curb the effects of climate change, many scholars have researched the motivators for the adoption of climate change adaptation strategies in agriculture. Many studies have been conducted on farmers' adoption of climate change adaptation strategies for many crops, such as maize (Bedeke et al., 2019), cassava (Omodara et al., 2023), food crops (Kassaye et al., 2021), potatoes (Andati et al., 2022), rice (Ojo et al., 2023), among others. However, little work has been done on the practices adopted by coffee farmers to adapt to climate change and their driving factors, especially in Northern Uganda, a region that heavily depends on agriculture to feed the population (MAAIF, 2022). Thus, it is imperative to study how coffee farmers in Northern Uganda adapt to the adverse effects of climate variability and their determining factors.

Determinants of adaptation strategies to climate change

Socio-economic factors

There is no consensus on the determinants of adaptation strategies to climate change based on the results reported by many authors. There is a lot of inconsistencies in the results reported across different areas. The number of years a farmer has been practicing crop production can be a significant determinant of the adoption of climate change adaptation strategies. Yatich et al. (2024) and Pandeya et al. (2024) assessed the covariates responsible for the adoption of climate change adaptation technologies. Their findings showed that farming experience is a negative significant predictor of the adoption of climate change adaptation strategies. Thus, as the farmer gains more years in farming, they become less adopters of the CCASs. On the contrast, the results from a study by Atube et al. (2021) as farmers gain more years in farming, they become better adopters of CCASs such as fallowing and agroforestry as climate change adaptation strategies.

The size of land a farmer has can be a predictor of the adoption of climate change adaptation strategies. The existing literature has presented mixed results on the relationship between farm size and the adoption of climate change adaptation strategies. Mwinkom et al. (2021) reported that the size of land has a negative effect on the adoption of climate change adaptation strategies such as timely planting and mixed framing methods. However, farm size did not have significant effects on adoption of other CCASs, such as early maturing and drought resistant varieties. Strikingly, the econometric results from Belay et al. (2017) depicted a different result showing that the size of land available to the farmer has a positive relationship with adoption of climate change adaptation strategies. Implying that farm size increases the probability of adoption of climate change adaptation strategies. In Vietnam, Ferrer et al. (2023) results further indicated that farm size does not have a significant effect on the adoption of CCASs.

Some of the CCASs such as inorganic fertilizer and pesticides, require capital to purchase and adopt on farms. As such, farm income plays a key role in adaptation to climate change. According to Kassa and Abdi (2022) farm income is positively associated with high adoption of CCASs. They reported that income is associated with high adoption of CCASs by 1.4% in Ethiopia. However, Atube et al. (2021) observed that farm income does not significantly predict farmers' decision to embrace CCASs such as improved and drought resistant varieties but positively influences the adoption of agroforestry and inorganic fertilizer.

Demographic factors

Marie et al. (2020) studied the relationship between socio-economic and institutional factors on adoption of climate change adaptation strategies in Ethiopia. Their econometric estimation showed that farmers' age positively influenced the adoption of income source diversification as one of the CCASs. Their also reported that age has no significant effect on the adoption of mixed farming, early and late planting, soil and water conservation and use of improved seeds as farmers' adaptive strategies to climate variability. On the other hand, the multivariate probit results from a study conducted in Ghana by Mwinkom et al. (2021) reported conflicting results, which showed that farmers' age negatively influences the adoption of timely planting and different farming methods as climate change adaptation strategies.

The gender of the household head may potentially predict farmers' decision to practice CCASs. According to Boudalia et al. (2024), there is a gender gap in the adoption of CCASs among farmers. In Northern Uganda, Atube et al. (2021) results showed that male headed households have higher probability of adoption fertilizers and pesticides as CCASs since they have adequate finances to purchase these capital demanding practices. Surprisingly, the findings of Pandeya et al. (2024) revealed that the gender of the household head does not significantly predict the adoption of CCASs among farmers. This also affirms the inconsistencies in the findings of the effect of gender on the adoption of CCASs.

Household size can be a significant predictor of the adoption of CCASs among farmers. However, there have been inconsistencies in the relationship between household size and the adoption of CCASs. In Ghana, the econometric results from a study by Mwinkom et al. (2021) depicted a negative relationship between the adoption of timely planting as an adaptation strategy to climate change and household size. Their results further showed that there no significant effect of household size on adoption of other CCASs like early maturing and drought resistant varieties. In contrast, the results from a study by Belay et al. (2017) appreciated the role of household size in the adoption of climate change adaptation strategies such as crop-livestock diversification, soil and water conservation practices.

Physical factors

In Kenya, Andati et al. (2022) explored the factors affecting the adoption of climate smart practices among smallholder farmers. Their results showed that an increase in market distance is positively associated with the adoption of climate smart agricultural practices such as soil nutrient management and water harvesting. On the contrary, the findings from a study by Kule et al. (2025) reported negative effects of market distance on adoption of CCASs such as mulching, minimum tillage, water harvesting and timely harvesting among farmers in Uganda.

A study conducted by Bibi (2025) considered distance to roads as one of the factors that can potentially influence farmers' adaptation strategies to climate change. From their binary logistic regression results, the distance to roads came out as a negative but statistically insignificant predictor of the adoption of climate change adaptation strategies among farmers in Pakistan.

Institutional factors

Credit plays a key role in climate financing. Thus, credit could have a significant relationship with the adoption of climate change adaptation strategies among farmers. However, the Tobit model results from a study conducted in Nigeria by Kalu and Mbanasor (2020) indicated that farmers who had access to credit were less likely to adopt climate change adaptation strategies than their counterparts who had access to credit. On the other hand, Ndiwa et al. (2024) observed a positive effect of credit on the adoption of irrigation practices and a negative effect of credit on the adoption of cover crops in Kenya. Similarly, Omodara et al. (2023) results depicted that credit increases the likelihood of adopting organic manure, crop rotation and fallowing in Nigeria.

In Northern Uganda, Atube et al. (2021) affirmed the roles and importance of extension on farmers adaptation to climate change. They observed that extension is associated with increasing adoption of agroforestry as a CCASs. This is due to the training and demonstrations offered by extension officers. Farmers who are subjected to such training via agricultural extension are more likely to adopt CCASs than their counterparts. However, the results depicted by Mugisha et al. (2025) in Uganda, depicted that extension is not positively associated with the adoption of CCASs among farmers. This might be as a result of the types and sources of extension the farmers accessed.

Group affiliation is also another socio-economic predictor of adaptation to climate change. Group members normally meet and discuss various issues, including boosting agricultural productivity through the adoption of climate smart practices. However, other groups are purposively formed to support farmers through credit, among others. Thus, group membership may significantly influence CCASs adoption among farmers. On the contrary to the hypothesis, Mthethwa et al. (2022) results from the Poisson model showed that group associations have a negative but insignificant, implying that membership to associations has no effect on farmers' adoption of CCASs. In line with this hypothesis, Saadu et al. (2024) results affirmed that group membership increases the adoption of CCASs in Western Nigeria.

Takele et al. (2019) analyzed the factors responsible for the adoption of climate change adaptation strategies in Ethiopia. From their findings, it is evident that distance from the market had a significant negative effect on the adoption of climate change adaptation strategies such as high yielding crop varieties. They also showed a positive relationship between market distance and the adoption of irrigation technologies, agroforestry and strip cropping. On the contrary, a study done by Asravor (2023) showed that the distance to the market had a positive relationship with the adoption of mono-cropping and mixed cropping irrigations and a negative effect on mixed farming rain fed adaptation strategies to climate change. In Somalia, Odawa et al. (2024) reported an insignificant effect of market distance on the adoption of climate change adaptation strategies among smallholder farmers.

The mixed and conflicting results on the determinants of the adoption of farmers' adaptation to climate change globally imply that every region is unique and possesses different socio-economic, environmental and policy attributes. Thus, it is highly important to have more region specific studies on the determinants of the adoption of climate change adaptation strategies. In Uganda, farmers' adoption of CCASs and their determinants have not been adequately explored. This study therefore aims to assess the types of climate change adaptation strategies employed by farmers and their determinants in Northern Uganda. The results will provide key policy implications that can boost coffee farmers' productivity, thereby making them economically productive.

Theoretical perspectives

Farmers' decision to adopt a given climate change adaptation strategy heavily relies on their perception of that CCAS (Atube et al., 2021). With the objective of maximizing their farm output, farmers are more likely to adopt CCASs that offer higher economic returns under a set of resource constraints. Thus, the adoption of CCASs is underpinned by utility maximization theory (UMT). It is evident in the UMT that rational farmers adopt a given CCAS, such as inorganic fertilizer, if it presents higher utility u under a set of limited resources. Moreover, the adoption of many CCASs is possible if farmers perceive the bundle of CCASs to contain higher utility. This can be a result of water conservation, reduction on soil erosion, minimizing pests and disease attack, improving soil fertility, resulting in higher coffee productivity. For example, if a farmer perceives inorganic fertilizer as having benefits such as boosting soil fertility, he is more likely to adopt it (Midamba et al., 2025). Thus, the utility as a result of adoption U_1 should be higher than the utility earned when the CCAS is not adopted U_0, i.e. $U_1 - U_0 > 0$. The adoption can also be influenced by other covariates X_j as shown in Table 1.

Conceptual model

The study's conceptual model is presented in Figure 1. The model outlines three key categories of predictors of the adoption of climate change adaptation strategies among smallholder farmers. These include socio-economic factors and institutional factors. These predictors may potentially increase or decrease the intensity of adoption of climate change adaptation strategies. This work considered adaptation strategies such as mulching, cover crops, organic fertilizers, inorganic fertilizers, crop rotation, agroforestry and minimum tillage as adaptation strategies among smallholder farmers in Uganda. These practices increase resilience to climate change, resulting in high coffee productivity. With high productivity, farmers have adequate finances to purchase foods, making them food secure.

Table 1. Explanatory variables.

Explanatory variables	Brief description and variable measurement	Expected effects	Citation
District	Farmers in Nwoya have higher access to advisory services and may be higher adopters of CCAS (1-Nwoya, 0-Otherwise)	±	Aniah (2024); Uganda Bureau of Statistics (UBOS) (2022)
Gender	Plots managed by male farmers may have higher adoption of CCAS than those managed by female farmers (1-Male, 0-Otherwise)	+	Agbenyo et al. (2022); Atube et al. (2021); Nchanji et al. (2022)
Age	Age comes with fatigue, leading to low adoption of CCAS among older farmers (Years)	−	Odawa et al. (2024); Wekesa et al. (2018)
Education	Education acts as a pathway to skills enhancement, leading to higher adoption of CCAS (Years)	+	Makate et al. (2019); Mthethwa et al. (2022); Muriithi et al. (2021); Sanogo et al. (2023)
Marital status	Married farmers share family ideas including how to maximize farm returns through the adoption of CCAS (1-Married, 0-Otherwise)	±	Mthethwa et al. (2022); Odawa et al. (2024)
Farming system	Large-scale farmers are driven by a return to farm investment maximization and can easily adopt the CCAS more than small-scale farmers (1-Large scale, 0-Otherwise)	+	Atube et al. (2021); Kifle et al. (2022); Zaehringer et al. (2021)
Household size	Household size can have either a positive or a negative effect on the adoption of CCAS technologies (Number of household members)	±	Agbenyo et al. (2022); Aniah (2024); Mthethwa et al. (2022)
Farming experience	Farming experience increases the pace of use of CCAS among the farmers, highly experienced farmers acknowledge the benefits of CCAS (Years)	+	Kumar et al. (2023); Massresha et al. (2021)
Group membership	Farmer groups act as the platforms for agricultural information sharing, leading to higher adoption of CCAS among group members (1-Member, 0-Otherwise)	+	Ndiwa et al. (2024); Sanogo et al. (2023)
Access to training	Advisory services such as training on CCAS cultivate awareness and skills on the use of CCAS among farmers, leading to a higher adoption rate among farmers who have access to the trainings (1-Has access to trainings, 0-Otherwise)	+	Ferrer et al. (2023); Gemeda et al. (2023); Kumar et al. (2023); Marie et al. (2020)
Access to farm inputs	Farm inputs such as land, seeds and fertilizers increase the adoption of CCAS among the farmers since they are driven by a return to investment maximization (1-Yes, 0-Otherwise)	+	Saadu et al. (2024)
Market linkages	Market linkages increase the use of CCAS among farmers (1-Has access, 0-Otherwise)	+	Abid et al., (2015; Kimani (2015); Marie et al. (2020)
Market distance	Shorter market distances reduce transportation costs while increasing access to CCAS among the farmers (Kilometers)	−	Abid et al. (2015); Arslan et al. (2014); Kassa and Abdi (2022); Ndiwa et al. (2024)
Extension visits	Extension visits increases adoption of CCASs (Ugandan shillings)	+	Atube et al. (2021); Odawa et al. (2024)
Land size	Land size increases farm income, which increases the rate of adoption of CCASs (Acres)	+	Kule et al. (2025)

Materials and methods

Study area

The study was conducted in Northern Uganda where coffee farming was promoted (Figure 2). This region has 30 districts, with a population of 8,513,720, representing 18.5% of the Ugandan population. The Northern part of Uganda is characterized by high temperatures, which can go as high as 40 °C. Despite the harsh weather, the occupants in this region have resorted to agriculture as their main economic activity. Crops such as maize, beans, cassava, sweet potatoes, coffee and cotton are all produced by smallholders in Northern Uganda. Attributed to the fertile soils in this region, coffee farming is highly promoted in areas such as the Nwoya and Oyam districts. Other economic activities include trade, hotels and restaurants, among others. However, the majority of the occupants in this region suffer from poverty and food insecurity, which are partly attributed to climate change ((Uganda Bureau of Statistics (UBOS), 2022). Being located in Northern Uganda, the Nwoya and Oyam districts are highly vulnerable to climate change due to their high temperatures, which can go as high as 40 °C. Furthermore, the farmers in these two districts have low adaptive capacity to climate change since the majority of credit-constraint smallholder farmers, resulting in adverse effects of climate change on agricultural productivity (MAAIF, 2016). In addition, farmers in Nwoya and Oyam are depend on rain fed agriculture, which is mostly affected by climate change, manifested in drought, floods, high temperatures, among others. Despite their high vulnerability to climate change, coffee farming is promoted in these two districts to uplift farmers from

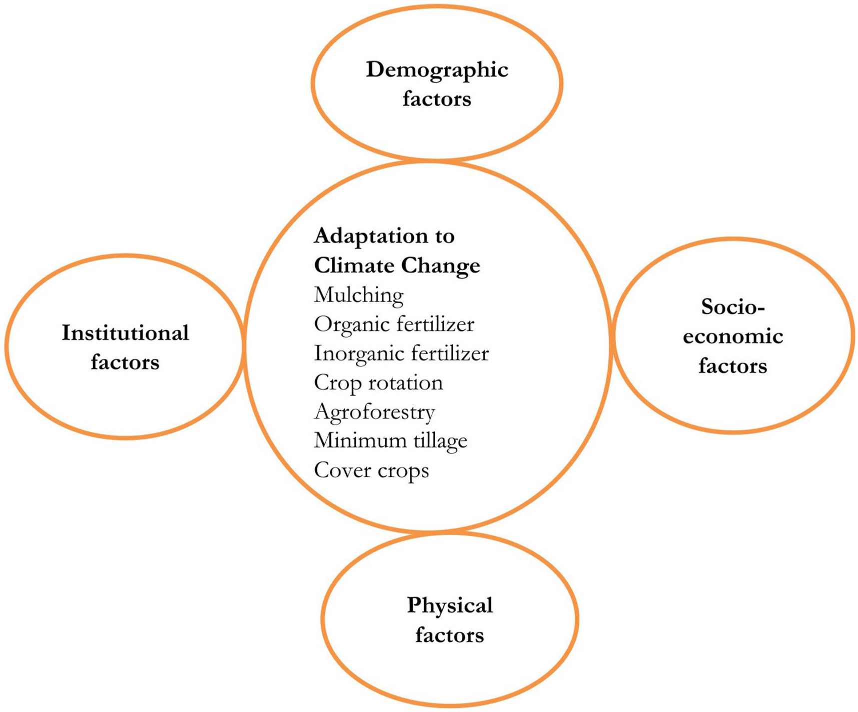

Figure 1. Conceptual model.

poverty and improve their living standards (Swaibu and Odokonyero, 2014). This is because the two districts have fertile soil that promotes coffee production. The profiles of these two districts are further discussed below.

Nwoya district

The Nwoya District was founded in 2010 (Figure 2). The district covers an area of 4170.6 km^2. Its bordering districts include the Omoro, Oyam, Kiryandongo, Bullisa, Pakwach and Amuru Districts (UBOS, 2018). There are 11 sub-counties, three town councils, 95 wards and 128 villages in the Nwoya district. It has a population of 133,506, with an average family size of five members per household. This population is dominated by different tribes, mostly Langi and Acholi, who engage in different economic activities. The district receives annual rainfall ranging from 1000 to 1500 mm, which is evident from March to July and from September to November annually. The district is endowed with fertile soils that support farming. As such, agriculture is the main economic activity of Nwoya occupants. Farmers engage in both crop and livestock production. Maize, beans, cassava, sweet potatoes, millet, sorghum, peas and bananas dominate the Nwoya district. Sheep, goats, cattle, chickens and donkeys are the main livestock reared by farmers in this region.

Oyam district

The Oyam District was founded in 2006 (Figure 2). This district is also located in the northern region of Uganda. Its bordering districts include Gulu, Pader, Kole, Apac, Kiryandongo and Nwoya. Oyam lies on 02 14N, 32 23E as district coordinates. According to a recent census, there are 378,900 people in Oyam. There are 7 sub-counties, 40 parishes and 699 villages in the district. Like Nwoya, sustainable agriculture is the main economic activity in Oyam District. Adequate rainfall and fertile soil are present in many parts of the Oyam district, which has led to the success of agricultural activities. The main crops produced in Oyam include cotton, bananas, matoke, beans, millet, pineapple, cassava and sweet potatoes. The reared livestock species include cattle, goats, sheep, pigs, chickens and sheep. Oyam is also composed of mixed tribes, including Langi and Acholi. Coffee production was highly supported in both districts. The Ugandan Coffee Development Authority has invested in input provision and training on climate-smart agricultural

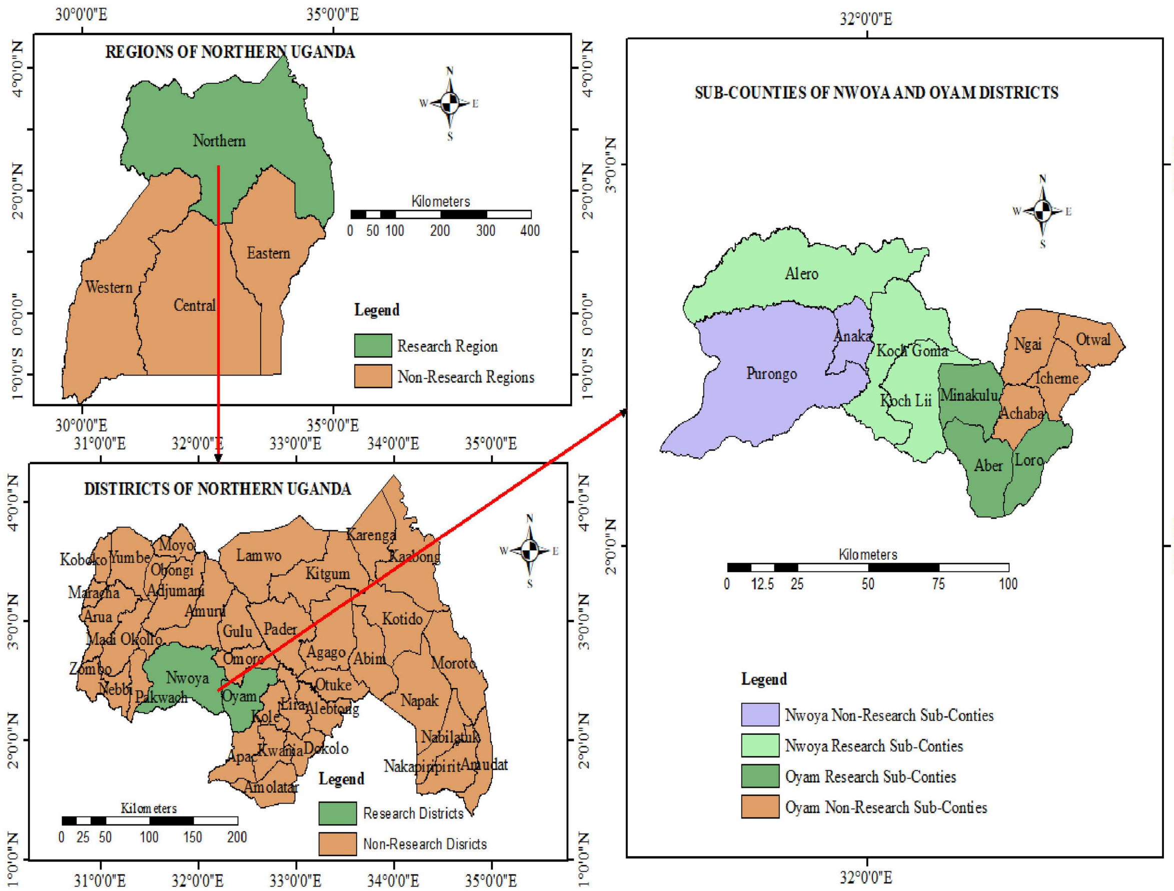

Figure 2. Study area.

practices that support coffee production. This has attracted many farmers who have allocated their lands to coffee production because of the availability of inputs from the Uganda Coffee Development Authority (UCDA, 2012).

Sampling procedure

Multistage sampling approach was employed to collect data from farmers in the Nwoya and Oyam districts (Figure 3). The two districts were purposively selected for the study because of the presence of a large number of coffee farmers, who were our target respondents. Moreover, several projects and interventions in these districts support coffee producers, such as training on climate smart agricultural practices and input support from the Uganda Coffee Development Authority (UCDA, 2019). The study then narrowed down to six sub-counties in the two districts, where there were large numbers of coffee producers. Three sub-counties were selected from each district. These sub-counties include Loro, Aber and Minakulu (Oyam District) and Kochgoma, Lungulu and Alero (Nwoya District). These sub-counties were considered for data collection because they have several coffee farms. In the final, stage 8 villages were sampled for data collection. Farmers who were available at the time of the study were given equal opportunities to participate. In total, 202 farmers were interviewed for the final sample size. The sample size was proportionately allocated based on the population of coffee farmers in the two districts. A total of 120 farmers were sampled from Nwoya district while only 82 farmers were from Oyam. This is because Nwoya has relatively many farmers than Oyam district. At the village level, we adopted random sampling to give every farmer equal opportunity to participate in the study. The overall sample size was determined using Yamane (1965) sample size formula.

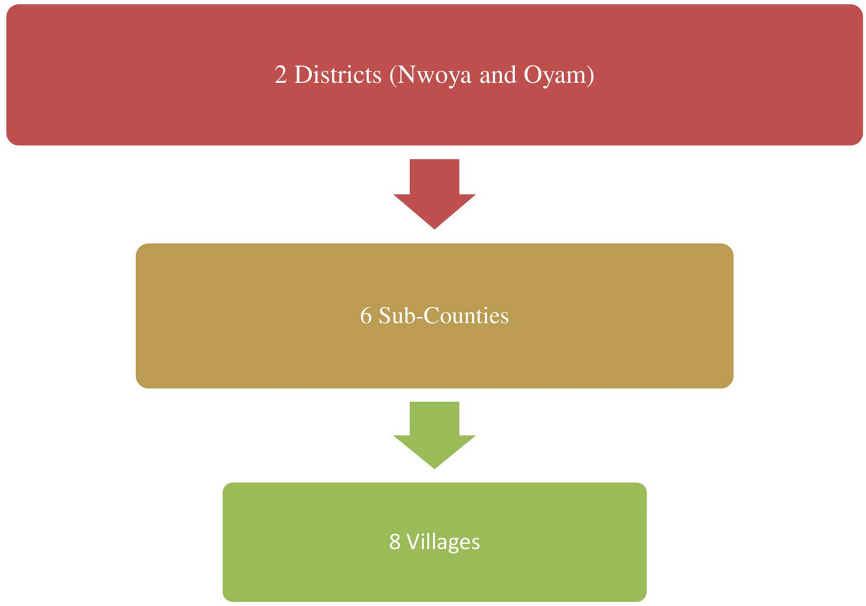

Figure 3. Sampling procedure.

$$n = \frac{N}{[1 + N(e^2)]},$$

$$n = \frac{400}{1 + 400(0.05^2)},$$

$$n = \frac{400}{1 + 400(0.05^2)}.$$

where; n represents the sample size, N represents the population size of coffee farmers in the two districts (400) (Alela et al., 2024) while e is the error term.

Data sources

This study relied on primary data collected from Nwoya and Oyam Districts of Uganda. After conceptualizing the research idea, a questionnaire was developed and pre-tested in the Gulu district to ensure that it would provide valid and reliable results (Hilton, 2017). This was followed by the revision of the tool and the rearrangement of some questions to ensure that the tool provided valid and reliable results that would answer the research questions. As a requirement by Gulu University, the study applied for ethical clearance from the Gulu University Research Ethics Committee. After presenting our research proposal, the study was approved by the Gulu University Research Ethics Committee, number GUREC-2021-46, to collect data from farmers. The study ensured that all ethical procedures, such as consent seeking, privacy and confidentiality, protection against harm and adherence to COVID-19 procedures, were followed and adhered to accordingly. Written informed consent for participation in the study was obtained from the farmers. Primary data were collected from coffee farmers through face-to-face interviews (Midamba et al., 2025). The choice of face-to-face interviews was based on the fact that it increased the concentration rate between the researcher and the respondent (Manzoor et al., 2020). The study enumerators were then hired and trained enumerators on data collection. Immediately after data collection, the data were entered into Excel and transferred to Stata version 16 for analysis. The study did not experience any challenges during data collection, such as the non-response rate, making the entire exercise run smoothly.

Econometric analysis

The multivariate probit model

There are several climate change adaptation strategy (CCAS) practices available to smallholder farmers. However, choosing a specific CCAS by a farmer is based on utility maximization theory (UMT). According to UMT, economic agents such as farmers (producers) are driven by profit maximization (Hess et al., 2018; Midamba et al., 2024). As such, they consider CCAS, which brings them higher economic returns, while considering the cost of adoption of such CCAS in a given farm (Atube et al., 2021). Atube et al. (2021) further explained that farmers would adopt a given CCAS if the expected benefits from use were higher than those from non-use, resulting in higher economic returns from the adoption of CCAS practices. According to Kassie et al. (2013), a multivariate probit model (MVP) is suitable for explaining the determinants of the adoption of multiple practices since the model takes care of the potential correlation among the unobserved disturbances in the adoption equations and the relationships between the adoptions of different CCASs practices. This is based on the fact that some CCASs can be complementary while others can be competing, leading to potential correlation and interdependence among the CCASs (Kassie et al., 2013). MVP has been applied by many scholars, such as; Kassie et al. (2013), who applied MVP adopt assess the determinants of the adoption of sustainable agricultural practices in Tanzania; Kwadzo and Quayson (2021) used MVP to explore the factors affecting the adoption of integrated soil fertility management practices in Ghana; and Oyetunde-Usman et al. (2021), who also used MVP to assess the determinants of sustainable agricultural practices in Nigeria. Following Kassie et al. (2013), the MVP model has a set of binary (dichotomous) dependent variables, denoted as Y_{abc}. In this study, these include binaries derived from the adoption of mulching, cover crops, crop rotation, minimum tillage, organic fertilizer, agroforestry and inorganic fertilizer, such that;

$$Y_{abc} = X'_{abc}\beta_j + u_{abc}, \text{ where } j = 1,2,3\ldots, \tag{1}$$

And that,

$$Y_{abc} = \begin{cases} 1 \text{ if } Y_{abc} > 0 \\ 0 \text{ if otherwise.} \end{cases} \tag{2}$$

In Equations (1) and (2), Y_{abc} represents the binary dependent variables, X'_{abc} represents the independent variables in Table 1, β_j represents the regression coefficients while u_{abc} represents the error term. However, where a rational h^{th} farmer chooses multiple CCASs, the error terms jointly follow multivariate normal distribution with zero conditional mean and variance normalized to unity, where $u_{abc} \sim \text{MVN}(0, \Omega)$ and the covariance matrix Ω is given in Equation (3);

$$\Omega = \begin{bmatrix} 1 & p12 & p13 & p14 & p15 & p16 & p17 \\ p21 & 1 & p23 & p24 & p25 & p26 & p27 \\ p31 & p32 & 1 & p34 & p35 & p36 & p37 \\ p41 & p42 & p43 & 1 & p45 & p46 & p47 \\ p51 & p52 & p53 & p54 & 1 & p56 & p57 \\ p61 & p62 & p63 & p64 & p65 & 1 & p67 \\ p71 & p71 & p73 & p74 & p75 & p76 & 1 \end{bmatrix}. \tag{3}$$

The off-diagonal elements in the covariance matrix represent the unobserved correlation between the error components of the different types of CCASs.

Results

The socio-demographic characteristics of farmers tend to change over time, which is attributed to the continuous changes in weather and climate, government policies, farmers' perceptions and preferences, input and output prices and soil types, among others. It is therefore recommended to establish the socio-demographic characteristics of the farmers over time. In this study, Table 2 summarizes the socio-

Table 2. Farmers' socio-demographic characteristics.

Variables	Measurement	Mean	Min	Max
Age	Years	56.35	22	86
Education	Years	9.00	0	12
Household size	Number	9.00	1	27
Experience	Years	29.34	4	60
Market distance	Kilometers	8.87	1	24
Total land size	Acres	9.62	1	200
Coffee land size	Acres	1.75	0.05	12
Number of coffee plants	Number	7631	100	16,000
Gender	1-Male, 0-Otherwise	0.88	0	1
Farming system	1-Large scale, 0-No	0.57	0	1
Group membership	1-Yes, 0-Otherwise	0.88	0	1
Credit access	1-Yes, 0- Otherwise	0.77	0	1
Extension	1-Yes, 0-Otherwise	0.99	0	1
District (Oyam)	1-Oyam, 0-Otherwise	0.59	0	1
District (Nwoya)	1-Nwoya, 0-Otherwise	0.41	0	1

demographic characteristics of the coffee farmers in Uganda. Farmers' age was 56.35 years old on average, with a mean of 29.34 years of experience. Ahimbisibwe et al. (2023) observed that coffee farmers' age in Uganda ranges from 30 to 45 years. This shows that the farmers had adequate experience about the climate change adaptation strategies that they needed to adopt on their coffee farms. The mean age also shows that the farmers had the potential to adopt the CCASs. The education level was mainly lower secondary, as evident from the average of 9 years spent in school. With nine years spent in school, farmers can easily scan and synthesize the best CCASs for their farms. In Northern Uganda, Okello et al. (2019) reported that farmers spent a mean of 6 years in school, depicting that they achieved up to primary level.

There was a large household size among the farmers, with an average of nine household members. This signifies the labor available for implementing the CCASs, as most of the farmers in Uganda source their farm labor from their households. This is similar to the findings of Alela et al. (2024), who also reported a mean household size of nine members among coffee farmers in Norther Uganda. The results further show that farmers are located far away from the market centers. This implies that access to inputs and output markets, among other agricultural services, is a bit challenging in these districts, as most of the agricultural advisory services, inputs and outputs are sourced from markets. Specifically, the average distance from farmers' homes to the nearest trading areas was 8.87 kilometers.

The farmers were characterized by a large land acreage. They had a mean of 9.62 acres of land, from which they allocated 18% to coffee farming (Alela et al., 2024). The large land acreage opens doors for more coffee farming plots for farmers. The farmers planted a mean of 7631 coffee plants on their farms. Attributed to the fact that coffee is a cash crop, coffee farming was dominated by male farmers (Alela et al., 2024). Institutional issues such as group membership, extension and credit access attracted 88%, 99% and 77% of the farmers, respectively. With the high rate of access to institutional and advisory services, farmers could utilize the opportunity to implement the CCASs. The results also showed that 57% of the farmers were large scale farmers. It is also evident that the majority of the farmers (59%) were from the Oyam district.

Adoption of climate change adaptation strategies

This study considered seven climate change adaptation strategies that farmers can use inexpensively and easily (Figure 4). These include cover crops, crop rotation, mulching, minimum tillage, organic fertilizer, agroforestry and inorganic fertilizer. From the results, the highly adopted CCAS was agroforestry (93.56%). Agroforestry is the practice of incorporating coffee plants with other trees (natural or planted). The high proportion of farmers who adopted agroforestry implies that coffee can do well with other trees without still competition for resources. Moreover, agroforestry is a multipurpose CCAS that serves as a cover crop and 'rain attraction' and provides a source of income to farmers, besides the income from coffee production.

Moreover, 83% of the farmers adopted cover crops. This is attributed to the low cost of purchasing cover crops, such as sweet potatoes, which are cheap and readily available to farmers. In addition, other agroforestry trees can be directly used as cover crops. Thus, attracting many farmers. Mulching and crop

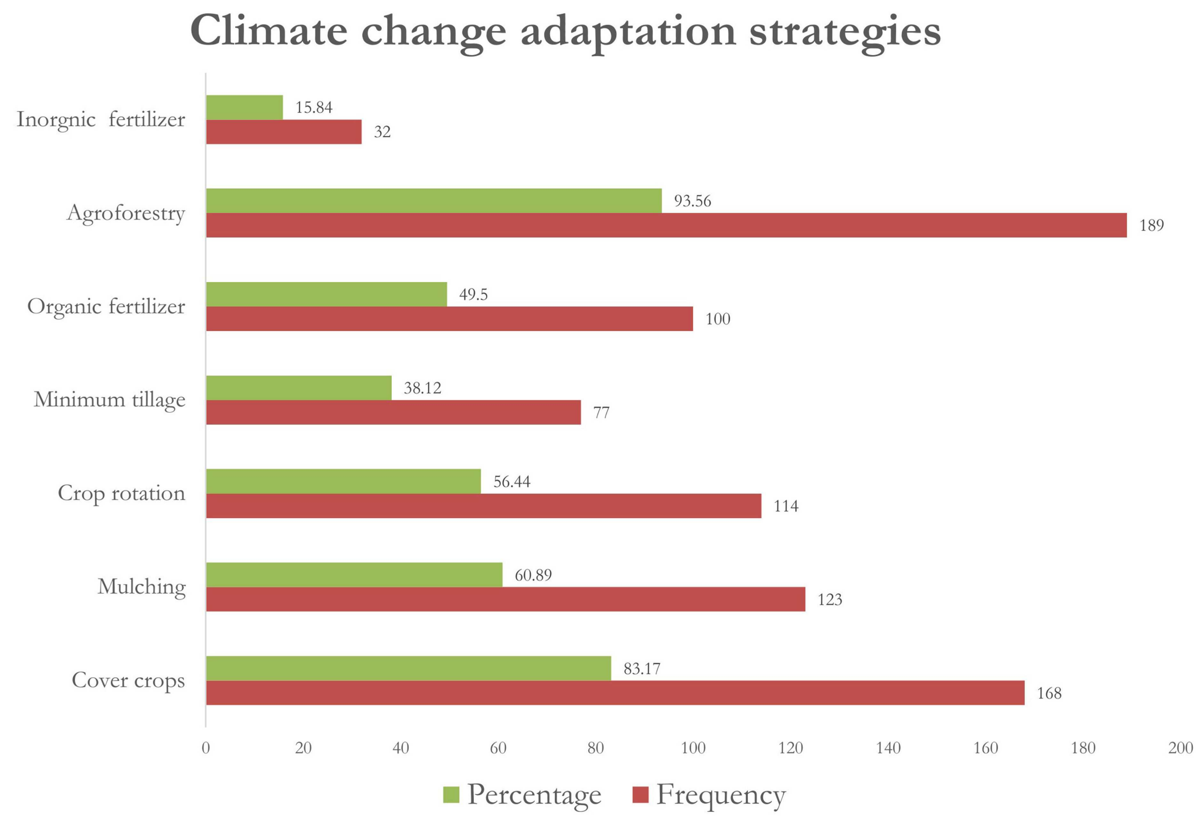

Figure 4. Climate change adaptation strategies employed by the farmers.

Table 3. Perceived benefits of climate change adaptation strategies.

Benefits of climate change adaptation strategies	Frequency (*N*)	Frequency (%)
CCASs increase crop yields	161	80.000
CCASs increase the quality of the yields	154	76.230
CCASs reduce the costs of production	162	81.200
CCASs increase soil fertility	169	83.660
CCASs reduce crop pests and diseases	173	85.640
CCASs control and reduces soil erosion	142	70.300

Note: CCASs represents climate change adaptation strategies.

rotation were adopted by 62% and 56.44% of the farmers, respectively. Mulching materials, such as tree branches, grass and leaves, are also cheap and readily available, thus attracting the majority of farmers (Nzeyimana et al., 2017). Mulching helps preserve soil moisture, reduces soil erosion and improves soil nutrients, especially after decomposing. There was low adoption of CCAS, such as minimum tillage (38.12%), organic fertilizer (49.5%) and inorganic fertilizers (15.84%), among the farmers. Inorganic fertilizers' low adoption is attributed to their high prices (Midamba et al., 2025) because most rural farmers are financially challenged (Bayite-kasule, 2005). The adoption rate of these practices sheds light on the need to incorporate many CCASs to achieve a full adoption rate. It is worrying to see that CCASs such as minimum tillage, organic fertilizer and inorganic fertilizers were embrace by a mere number of farmers.

Perceived benefits of climate change adaptation strategies

There are several benefits to adopting climate change adaptation strategies by farmers. In this study, the farmers reported six major perceived benefits of adopting climate change adaptation strategies on their farms (Table 3). Farmers reported that climate change adaptation strategies increase crop yields, resulting in higher returns to farm investment. This not only increases their living standards but also increases farm income and food security. This closely aligns with Akter et al. (2022) who observed yield increment as a result of the CCASs adoption in Bangladesh. This is achieved through many roles, including water conservation, the reduction of soil erosion and the prevention of soil nutrients, among others.

The results further showed that 76% of the farmers noted that these practices increased the quality of crop yields. For example, quality coffee is evident when they adopt these practices. This is attributed to a reduction in pests and diseases on farms. Similarly, CCASs such as minimum tillage and mulching increase soil water retention, resulting in quality coffee output among adopters (Asmare & Paul, 2025). With increased coffee quality, they can fetch better market prices, which makes them economically stable. Similarly, 81.20% of the farmers highlighted that the practices helped reduce the costs of production. Climate change adaptation strategies such as mulching and cover crops helped to preserve soil moisture, helping farmers reduce and save on the cost of farm irrigation. The costs associated with pest and disease control are easily reduced when farmers adopt climate change strategies such as crop rotation. A study by Zheng et al. (2024) the role of CCASs in reduction the crop production costs among farmers. Thus, many farmers have adopted CCASs in order to reduce production costs and maximize the net returns from coffee production.

In addition, farmers perceive that these practices increase soil fertility and reduce soil erosion. This is because of the adoption of practices such as cover crops, which ensures that the topsoil is not swept away by water run-offs. Mulching is a source of nutrients, despite the water conservation roles. Other practice such as organic and inorganic fertilizers, also boost soil fertility by providing the required soil nutrients (Bonabana-Wabbi et al., 2016; Mugwe et al., 2009). Finally, 85.640% of the farmers reported that these practices helped control the infestation of pests and diseases. These perceived benefits of CCAS are in line with those of other researchers, such as Aryal et al. (2020); Kassa and Abdi (2022); Saadu et al. (2024); Thornton et al. (2014) and Zhao and Li (2015). The authors opined that these CCASs present a wealth of benefits that improve farm productivity and climate resilience and improve farmers' adaptive capacity.

Multicollinearity test

Following Akinwande et al. (2015), there should be no high correlation among the independent variables. To test for the presence of multicollinearity, the study adopted variance inflation factor (VIF) test. Hauser et al. (2016) opined that the VIF should be less than 10 and more than 1 to meet the multicollinearity threshold. The results in Table 4 indicate minimum and maximum VIF of 1.12 and 2.23, respectively. This implies that the independent variables were not correlated with each other.

Correlation coefficients of the CCASs

The correlation of adoption of the CCASs are presented in Table 5. The results showed that there was a significant correlation between different CCASs. For example, there was a positive significant correlation between the adoption of mulching and cover crops. This implies that the two are complementary. The positive correlation between mulching and cover crops may be as a result of the fact that farmers can use some of the cover crops leaves as mulches, thus complementing each other. Organic and inorganic

Table 4. Multicollinearity test.

Explanatory variables	VIF	1/VIF
District	2.23	0.448
Gender	2.16	0.462
Age	2.22	0.450
Education	1.56	0.640
Marital status	2.15	0.465
Farming system	1.35	0.738
Household size	1.53	0.651
Farming experience	1.96	0.510
Group membership	1.15	0.866
Access to trainings	1.40	0.712
Access to farm inputs	1.32	0.754
Market linkages	1.35	0.739
Market distance	2.12	0.472
Extension visits	1.12	0.890
Mean VIF	**1.69**	

Table 5. Correlation coefficients of the CCASs.

CCASs	Cover crops	Mulching	Crop rotation	Minimum tillage	Agroforestry	Organic fertilizer	Inorganic fertilizer
Cover crops	1						
Mulching	0.317***	1					
Crop rotation	0.378***	0.277***	1				
Minimum tillage	0.135**	0.190***	0.257***	1			
Agroforestry	−0.010	0.120*	−0.067**	0.122*	1		
Organic fertilizer	0.339***	0.489***	0.270***	0.405***	0.219***	1	
Inorganic fertilizer	0.086	0.097	0.189***	0.106	0.113	0.139**	1

Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho71 = rho32 = rho42 = rho52 = rho62 = rho72 = rho43 = rho53 = rho63 = rho73 = rho54 = rho64 = rho74 = rho65 = rho75 = rho76 = 0: Wald chi2(98) = 234.650.
***, ***, * 1%, 10% and 5% significance.

fertilizers were positively correlated. This is because farmers who are credit constrained and cannot purchase inorganic fertilizer for the whole farm could supplement it with organic fertilizers. Since some mulching materials, such as tree leaves, grasses can also be used to prepare organic fertilizers, there was a significant positive correlation between organic fertilizers and mulching.

Other positively correlated CCASs include minimum tillage and organic fertilizers; agroforestry and organic fertilizers; crop rotation and inorganic fertilizers, among others. However, CCASs such as agroforestry and crop rotation were negatively correlated. This is because some crop varieties require adequate space and time, resulting in the cutting down of some trees to provide more space for new entrants. This reduces agroforestry adoption. The significant correlation among the CCASs has been evident in a number of studies in Sub-Saharan Africa such as Kassie et al. (2013) in Tanzania; Alemayehu et al. (2024) in Ethiopia; Enos et al. (2025) in Northern Uganda; Omodara et al. (2023) in Nigeria; Kwadzo and Quayson (2021) in Ghana and Nyang'au and Mohamed, 2020.

The significant correlation among the CCASs justifies the choice of Multivariate Probit regression for assessing the determinants of adaptation strategies to climate change among the farmers, due to the association between choosing different CCASs among the smallholder coffee farmers in Uganda (Alela et al., 2024; Kassie et al., 2013).

Determinants of farmers' adaptation strategies to climate change

Multivariate Probit model estimates indicate that socioeconomic factors have a significant influence on farmers' adaptation to climate change, as shown in Table 6. First, the summary results indicate that the model was statistically significant, implying that the regression coefficients are not equal to zero. The Wald chi2 value also showed that the model was adequate because its values fell within the acceptable range. The log-likelihood values also indicated that the model was adequate for this study.

From the MVP results, gender has a negative and significant effect on the probability of adoption of CCASs such as mulching and crop rotation. In addition, age has a negative effect on the probability of farmers' adoption of adaptation strategies such as cover crops and inorganic fertilizers and a positive effect on the adoption of crop rotation as a CCAS among farmers. The results further showed that the probability of the adoption of cover crops, mulching and organic fertilizers was positively predicted by education. As education years increase by a unit, the probability of adoption of these practices also increases significantly.

Large scale farmers were better adopters of cover crops and organic fertilizers. As such, the farming system positively influenced the adoption of cover crops and organic fertilizers as CCASs. An increase in household size was negatively associated with a higher probability of adoption of crop rotation. Farming experience was a negative predictor of the adoption of mulching and crop rotation and positively influenced farmers' adoption of crop rotation on their farms. It is further shown that climate change adaptation trainings significantly increase the probability of adopting mulching, minimum tillage and agroforestry among farmers.

In addition, it is evident that access to farm inputs positively influenced the probability of adoption of several climate change adaptation strategies. These include cover crops, mulching, crop rotation, minimum tillage, agroforestry and organic fertilizers. Farmers who had market linkages had a significantly low probability of adopting CCASs such as cover crops, crop rotation and minimum tillage. Distance to the

Table 6. Marginal effects for the determinants of adoption of climate change adaptation strategies.

Climate change adaptation strategies	Cover crops		Mulching		Crop rotation		Minimum tillage		Agroforestry		Organic fertilizer		Inorganic fertilizer	
Explanatory variables	dy/dx	*P* > z	dy/dx	*P* > z	dy/dx	*P* > z	dy/dx	*P* > z	dy/dx	*P* > z	dy/dx	*P* > z	dy/dx	*P* > z
District	−0.150***	0.001	−0.008***	0.001	0.201	0.454	0.794***	0.007	0.097	0.856	−0.527*	0.090	0.096	0.779
Gender	−0.199	0.698	−0.250**	0.013	−0.019**	0.033	0.229	0.600	−0.355	0.701	−0.783	0.101	−0.616	0.273
Age	−0.026**	0.022	0.008	0.415	0.017*	0.066	−0.003	0.744	0.006	0.681	0.013	0.210	−0.023*	0.062
Education	0.084**	0.014	0.067***	0.010	0.022	0.359	0.024	0.343	0.014	0.750	0.075***	0.003	0.053	0.198
Marital status	−0.052	0.763	−0.265	0.116	−0.198	0.209	−0.062	0.684	−0.029	0.924	−0.175	0.245	−0.038	0.859
Farming system	0.974**	0.031	0.259	0.357	0.272	0.248	0.301	0.230	0.451	0.383	0.578**	0.019	−0.339	0.280
Household size	−0.023	0.429	−0.064	0.981	−0.072***	0.005	−0.037	0.148	0.003	0.951	−0.037	0.157	0.016	0.650
Experience	0.020*	0.072	−0.020**	0.050	−0.037***	0.000	0.013	0.152	0.026	0.265	0.002	0.778	−0.009	0.412
Group membership	−0.335	0.385	0.346	0.303	0.646**	0.032	−0.127	0.670	−0.919	0.259	0.718	0.139	0.530	0.241
Access to CCAS trainings	−0.071	0.841	0.522*	0.100	0.117	0.666	0.025***	0.003	0.482*	0.100	0.097	0.743	0.506	0.276
Access to farm inputs	0.826**	0.015	0.563***	0.000	0.752***	0.003	0.791***	0.003	0.094*	0.091	0.998***	0.000	0.478	0.130
Access to market linkages	−0.729**	0.014	−0.202	0.462	−0.489**	0.042	−0.725***	0.003	−0.446	0.424	0.271	0.309	−0.225	0.451
Market distance	−0.048**	0.019	−0.043**	0.028	0.248	0.634	−0.043**	0.024	−0.023***	0.008	−0.012	0.500	−0.034	0.987
Extension visits	0.005	0.996	0.216**	0.017	0.008	0.052	0.079**	0.049	0.416**	0.037	0.193	0.123	0.277***	0.000
Prob>Chi2	0.000													
Log likelihood	−550.019													
Wald chi2 (98)	234.650***													

Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho71 = rho32 = rho42 = rho52 = rho62 = rho72 = rho43 = rho53 = rho63 = rho73 = rho54 = rho64 = rho74 = rho65 = rho75 = rho76 = 0:
*,**,*** 10%, 5% and 1% significance.

market was also a significant predictor of CCASs adoption. It negatively influenced the probability of adopting CCASs such as cover crops, mulching, minimum tillage and agroforestry. Lastly, extension visits positively predicted the probability of adoption of mulching, minimum tillage, agroforestry and inorganic fertilizers as climate change adaptation strategies.

Discussion

Demographic factors

Gender

The results suggest that gender is a predictor variable and plays a key role in the adoption of climate change adaptation strategies (Table 6). Male farmers had a lower probability of adopting mulching and crop rotation by 0.8 and 1.9 percentages points respectively than their fellow female counterparts. This is in line with the findings of Nchanji et al. (2022), who observed higher adoption of climate change adaptation strategies, such as fertilizers, improved seeds and early planting, among female farmers than among their male counterparts. The higher rate of adoption of mulching and crop rotation among female farmers may be attributed to the fact that female farmers are mostly tasked with taking care of farms, which includes mulching and crop rotation, while male farmers take decision-making roles, such as land allocation to farming. However, Atube et al. (2021) observed that male-headed households were more likely to adopt climate change strategies such as chemical fertilizers and pesticides than their female-headed counterparts. In Malawi, Nchanji et al. (2022) noted that the adoption of CCASs such as fertilizers and improved seeds were higher among women than men while men concentrated on irrigation adoption. The positive effect of gender on the adoption of mulching and crop rotation reveals gender disparities in the adoption of CCASs.

Age of the farmer

The findings also show that age significantly influenced farmers' adaptation strategies to climate change. The results showed that an increase in age by one year reduces the probability of adopting cover crops and inorganic fertilizers by 2.6 and 2.3 percentage points, respectively, and increase the probability of adopting crop rotation by 1.7 percentage points among the farmers. This is consistent with the findings of Kinyua et al. (2022). Age is associated with fatigue and low energy consumption. Older farmers are less active than their younger counterparts. This contributed to the low adoption of CCASs among older farmers. Similarly, cover crops require a large amount of energy, especially on large farms. As such, farmers who are old and have less energy may not adopt them easily unless they hire farm labor, which comes at a fee. However, crop rotation does not require lots of energy, leading to the higher likelihood of adoption of crop rotation among older farmers. Similarly, the findings of Gemeda et al. (2023) also affirmed that age negatively influences the adoption of the CCAS in Ethiopia. In contrast, Kalu and Mbanasor (2020) reported a positive effect of age on the adoption of CCAS among smallholders in Nigeria, arguing that older farmers are well-connected and have a wealth of social capital that increases the adoption rate. However, Laosutsan et al. (2019) reported a positive but insignificant effect of age on the adoption of the CCAS by farmers in Thailand. From the results, it is observed that age plays a key role in the adoption of cover crops, inorganic fertilizers and crop rotation.

Household size

Sub-Saharan Africa is characterized by high population growth, especially in rural areas where smallholder farmers reside. Farmers with many family members living in their households are less advantaged in adopting climate change adaptation strategies. They tend to use their little funds for food production and to meet other basic family needs, such as education and health. This results in fewer resources being apportioned to the adoption of climate change adaptation strategies. The findings of our study revealed that an increase in household size by one member would reduce the probability of adopting crop rotation by 7.2 percentage points. This is also attributed to the over-allocation of resources for household needs rather than adaptation strategies. In Uganda, Midamba et al. (2023) reported that a large household size decreases the probability of adopting agricultural technologies owing to the high dependency ratio, leading to the over-allocation of household resources to family needs. However, Faisal et al. (2021) argued that household members provide family labor, which can increase the adoption rate of labor-intensive practices on the farm. On the contrary, Aniah (2024) reported that the adoption of CCASs was high among large households in Ghana, implying that household size has a positive effect on the adoption of the CCAS. This may be attributed to labor provision in their farms. As such, policies targeting adoption of CCASs should put more focus on farmers' household sizes.

Socio-economic factors

Education

Education plays a key role in improving agricultural productivity. It is through education services such as adult literacy programs that farmers gain skills and awareness of the recommended climate change strategies to implement on their farms. The majority of studies have also shown that educated farmers are better performers than their non-educated counterparts. The results of this study showed that an increase in education by one unit would increase the probability of adopting cover crops, mulching and organic fertilizers by 8.4, 6.7 and 7.5 percentage points, respectively. The positive influence of education on the adoption of cover crops, mulching and organic fertilizers is a result of the wealth of skills and knowledge accrued to the educated farmers. They are able to reason well and assess the best CCASs for their farms than the non-educated counterparts. These results are similar to the findings of Makate et al. (2019), who reported that education plays a key role in the adoption of climate change adaptation strategies. Other studies, such as Kalu and Mbanasor (2020), have also pointed out the role of education in improving the adoption of climate change adaptation strategies, which in the long run improves farm productivity among smallholder farmers. Similarly, Muriithi et al. (2021) also reported a positive effect of education on the adoption of CCASs in Kenya. However, Gemeda et al. (2023) reported a negative and significant effect of education on the adoption of the CCAS among farmers in Ethiopia. An inverse effect of education on the adoption of CCASs was also reported by Mthethwa et al. (2022). Thus, education is a positive predictor of the adoption of cover crops, mulching and organic fertilizers and should be considered when implementing agricultural policies targeting the adoption of CCASs.

Farming system

Production size was also a significant predictor of the use of adaptation strategies among coffee farmers. Farmers who operated on a large scale were 0.974 times more likely to use cover crops and 0.578 times more likely to adopt organic fertilizers than small scale farmers. Large-scale farmers aim to earn the highest revenue from their farms. It is also believed that such farmers depend entirely on coffee farming as a major source of livelihood. To get the best out of their farming, such farmers adopt available climate change adaptation strategies that maximize yields. This is evident in adaptation strategies, such as inorganic fertilizers, which help farmers boost their farm output. Owing to their large portions of land, such farmers use cover crops to reduce soil erosion. In the long run, the adoption of these strategies is significantly higher among large-scale farmers than among those who practice small-scale coffee production (NEPAD, 2013). This is similar to the findings of Kifle et al. (2022). In their study, they observed that the farming scale positively influences the adoption of CCASs, as large-scale farmers are higher adopters. As such, the type of farming system of coffee farmers needs to be put into consideration when designing agricultural policies that promote the uptake of CCASs among farmers.

Coffee farming experience

Farming experience significantly influenced adoption of mulching, crop rotation and cover crops. An increase in farming coffee farming experience by a unit reduces the probability of adopting mulching and crops rotation by 2.0 and 3.7 percentage points and increases the probability of adopting cover crops by 2.0 percentage points. Farming experience is an important asset that improves farm productivity. Farmers with a wealth of years in farming have gained the necessary skills to help them evaluate the best CCASs that can increase their farm productivity. Based on their evaluations, they end up adopting some adaptation strategies while also rejecting others, which they consider as less important to their farms. This justifies the positive and negative influences of farming experience on the adoption of cover crops;

and mulching and crop rotation, respectively. Massresha et al. (2021) reported that farming experience is a positive predictor of the adoption of CSA strategies, such as irrigation, in Nigeria. Ogisi and Begho (2023) discussed the role of farming experiences in the adoption of climate change practices. Moreover, Kumar et al. (2023) reported a positive effects of farming experience on the adoption of CCAS in Southern India.

Market linkages

Market linkages had a negative influence on the adoption of adaptation strategies, such as cover crops, crop rotation and minimum tillage, among farmers. Our findings revealed that access to market linkages reduces the probability of adopting cover crops, crop rotation and minimum tillage by 7.3, 4.5 and 7.3 percentage points, respectively. Over the years, market linkages have been believed to promote the adoption of agricultural practices. However, the negative influence of market linkages on the adoption of CCASs can be linked to their type of market linkages. Market linkages that focus mainly on buying coffee may not promote the adoption of CCASs. However, those that consider production, such as contract farming, adopt practices that help farmers adapt to the adverse effects of climate change. In this study, farmers' linkages were mainly for selling their coffee without any role on the production side. This is consistent with the findings of Ferris et al. (2014), who appreciated the role of market linkages in smallholder agriculture. Similarly, the findings from the study conducted in Ethiopia by Marie et al. (2020) revealed that farmers with market access had a significantly higher probability of adopting CCASs compared to their counterparts without market linkages. The findings emanating from the study conducted by Abid et al. (2015) in Pakistan also reported that farmers who had access to market information through market linkages were higher adopters. Thus, the provision of the right market linkages that promotes the adoption of CCASs should be put into consideration.

Institutional factors

Membership and participation in farmer groups

Farmer group membership was a positive predictor of the adoption of crop rotation. Group membership increases the probability of adopting crop rotation by 64.6 percentage points among the farmers. The groups serve as meeting areas where farmers can gather to discuss their productivity, including how to improve their coffee yields through the adoption of these strategies. In these groups, farmers can come together to disseminate agricultural information, train themselves and organize peer farmer field visits to boost coffee output. In Southern Mali, Sanogo et al. (2023) also reported that group participants had a 92% higher probability of adopting climate-change adaptation strategies. The findings also conform with those of Ndiwa et al. (2024), who noted that group membership positively influences CCASs in Kenya, as farmers can learn from each other, purchase some of the CCAS as a group, and access other services such as agricultural extension, leading to higher adoption of CCASs among them. A review study conducted by Ogisi and Begho (2023) also appreciated the role of membership in farmer groups in the adoption of CCASs in Sub-Saharan Africa. Thus, it is concluded that group membership increases the adoption of crop rotation and should therefore be promoted.

Training on climate change adaptation strategies

Training on how to adapt to climate change had a positive influence on the adoption of mulching, minimum tillage and agroforestry among farmers. CCASs training increases the probability of adopting mulching, minimum tillage and agroforestry by 52.2, 2.5 and 48.2 percentage points, respectively. Training acts as a pathway through which farmers can learn and adopt these adaptation strategies on their farms. Training cultivates skills on how farmers can improve their yields through the adoption of CCASs on their farms. Through training, farmers can also network among themselves and share ideas on the best and available CCASs. Therefore, farmers who accessed and attended these trainings were much better off adopting these practices than their counterparts who did not participate in such training. Kinyua et al. (2022) also appreciated the role of climate change training after reporting a positive association between the adoption of CSA practices and CSA training among farmers in Kenya. This is also consistent with the findings reported by Kumar et al. (2023), who noted that farmers who have access to training on CCASs are higher adopters of CCASs than their fellows who do not participate in training in Southern India. In Malawi, Nchanji et al. (2022) also appreciated the role of training in the adoption of CCASs among framers. On the contrary, the findings reported by Marie et al. (2020) in Ethiopia showed that training in CCASs had no significant effect on farmers' adoption of CCASs in Ethiopia. To boost the uptake of mulching, minimum tillage and agroforestry, there is a need for CCASs-based trainings and demonstrations.

Access to farm inputs

Access to farm inputs such as land, seeds and agrochemicals was positively associated with the higher adoption of cover crops, mulching, crop rotation, minimum tillage, agroforestry and organic fertilizers. The results indicate that access to farm inputs increases the probability of adopting cover crops, mulching, crop rotation, minimum tillage, agroforestry and organic fertilizers by 82.6, 56.3, 72.5, 79.1, 9.4 and 99.8 percentage points, respectively. When a farmer has enough land and other inputs, they are motivated to increase their yields by adopting climate change adaptation strategies, such as cover crops, crop rotation, minimum tillage and inorganic fertilizers. A shortage of these inputs kills farmers' morale, leading to low agricultural productivity. Our results are in line with the findings of Midamba et al. (2023), who recommend subsiding farm inputs after reporting a positive effect of farm inputs on the adoption of climate-smart agricultural practices. Promoting access to farm inputs such as seeds, fertilizers and pesticides is a strategy for boosting uptake of cover crops, mulching, crop rotation, minimum tillage, agroforestry and organic fertilizers. This can be achieved by setting up farm input centers where farmers can access them easily.

Extension visit

The number of extension visits had a positive and significant effect on the adoption of mulching, minimum tillage, agroforestry and inorganic fertilizers. An increase in the number of extension visits by a unit would increase the probability of adopting mulching, minimum tillage, agroforestry and inorganic fertilizers by 21.6, 7.9, 41.2 and 27.7 percentage points, respectively. Extension officers offer training and advisory services to smallholder farmers on how to improve their farm productivity through embracing CCASs such as mulching, minimum tillage, agroforestry and inorganic fertilizers. The extension officers also convey relevant information on the availability of new agricultural technologies to be adopted by the farmers (Midamba & Ouko, 2024). This aligns with the findings of Kinyua et al. (2022), who also reported that extension services increase the extent of adoption of climate change adaptation strategies in Kenya. Similarly, Atube et al. (2021) also observed that farmers who had access to extension services were more likely to adopt agroforestry in Northern Uganda. On the contrary, the findings of Gemeda et al. (2023) suggested that farmers with access to extension were less likely to adopt the CCASs in Ethiopia. This was attributed to the type of extension services provided to the farmers. Thus, setting up more extension centers while increasing the extension person is more likely to boost the uptake of mulching, minimum tillage, agroforestry and inorganic fertilizers.

Physical factors

Farmers' distance to the market

The distance traveled by the farmer to the nearest trading area has a negative association with the adoption of cover crops, mulching, minimum tillage and agroforestry as adaptation strategies to climate change. An increase in the market distance by a kilometer reduces the probability of the adoption of cover cropping, mulching, minimum tillage and agroforestry by 4.8, 4.3, 4.3 and 2.3 percentage points, respectively. This is attributed to the fact that the longer the farmer travels to trading areas, the higher the transport fees they incur. In the trading areas, there are agricultural services and inputs, such as fertilizer, that farmers need. Therefore, farmers near marketplaces can access such services and inputs easily and promptly, unlike their distant counterparts. Distance to market areas, therefore, plays a key role in the adoption of CCASs among farmers. The shorter the distance, the better the farmers' adoption of practices. Arslan et al. (2014) also affirmed that market distance negatively influences the adoption of climate change adaptation practices. Okumu et al. (2023) also reported a negative effect of market distance on the adoption of CSA practices in Kenya. In Pakistan, the findings from Abid et al. (2015) also opined that distance to the market has a negative effect on the adoption of CCASs. Farmers who are near the market have higher probability of adopting CCASs than their counterparts who are located far from the market. However, Ndiwa et al.

(2024) reported a positive effect of market distance on the adoption of CCASs among farmers. When designing policies that promote CCAS adoption, it is imperative to consider the farmers who are located far from the market areas as well.

Conclusion

Coffee farming has the potential to improve the farmers' living standards through the high income generated from its sale. Farmers can use income to meet their daily needs. However, coffee production is also challenged by the adverse effects of climate change. This study examined the determinants of farmers' strategies to adapt to climate change in Northern Uganda. From the findings, the study concluded that agroforestry, cover crops, mulching and crop rotation are widely adopted climate change adaptation strategies among coffee farmers in Northern Uganda. On the other hand, organic fertilizers and inorganic fertilizers have been adopted by a few farmers. Farmers perceived these CCASs as highly beneficial in reducing the negative effects of climate change. The study also concluded that socio-economic variables such as gender, age, education, farming system, household size, farming experience, extension visits, group membership, access to training, market linkages and market distance significantly influence farmers' adaptation strategies to the effects of climate change. This work contributes by recommending the policies below that can boost the adoption of CCASs among the farmers in Northern Uganda.

Policy recommendations

From the multivariate probit results, it is important to offer practical training and demonstrations to farmers on climate change adaptation strategies and how to incorporate them into their farmers. This can be done by extension officers. In addition, farmers should be encouraged to come together in associations and groups where they can learn from each other and adopt climate change adaptation strategies on their farms. The groups serve as platforms where farmers learn and disseminate any agricultural information among them. Subsiding farm inputs would also increase the rate of adoption of CCASs since farmers are sometimes reluctant to adopt costly farm inputs such as inorganic fertilizers. Boosting farmers' literacy levels through access to adult education programs such as TV and Radio agricultural programs can also help increase the adoption of CCASs. Moreover, continuous training and demonstrations on the uptake of CCASs should be highly promoted by the government. Lastly, investing in more extension officers would increase the number of extension visits to smallholder farmers. This would result in a high extent of adoption of the CCASs in Northern Uganda.

Despite the findings are recommendations from this work, there are some limitations stemming from this study. First, the study relied on a small sample size of 202 farmers. Future studies should increase the sample size and capture more coffee-producing districts in other regions, such as Eastern and Central Uganda. The other limitation arising from the study is the failure to measure the impacts of CCASs on farm productivity among coffee farmers. Future studies should therefore assess the impacts of CCASs on coffee productivity.

Author contributions

CRediT: **Dick Chune Midamba:** Conceptualization, Formal analysis, Methodology, Writing – review & editing; **Beatrice Alela:** Conceptualization, Formal analysis, Methodology, Writing – original draft; **John Atsu Agbolosoo:** Formal analysis, Writing – review & editing.

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Informed consent

Written informed consent was obtained from all the participants.

Ethical approval

The study was approved by the Gulu University Research Ethics Committee under approval number: GUREC-2021-46.

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