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# Factors Influencing the Adoption of Climate-Smart Agriculture among Maize and Sorghum Farmers in Northern Ghana.

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## ABSTRACT

This study investigates the determinants of climate-smart agricultural practice adoption among smallholder maize and sorghum farmers in Northern Ghana, which is crucial for enhancing crop productivity and ensuring regional food security. By analysing data from 1,000 smallholder farmers through descriptive statistics, a transdisciplinary approach and a multivariate probit regression model, the study reveals a concerning overreliance on chemical fertilisers, constituting 56% overall adoption, 72% in the Northern Region and 51% in the Upper West. Contrary, conservation agriculture emerges as a promising practice, with a 56% adoption rate in the Upper East. Factors that determine the adoption include; farmer demographics, land tenure system, access to climate information, market availability, presence of agriculture extension officers, and geographical location. These findings underscore the urgent need for government investment in research, capacity building, and infrastructure in Northern Ghana to foster broader adoption of sustainable practices. This study offers significant insights into the dynamics of climate-smart agricultural adoption in the region, with implications for agricultural sustainability and food security.

## 1. Introduction

Agriculture plays a pivotal role in fostering economic growth and development, contributing significantly to the global domestic product (GDP) with a 4% share (Raj *et al.*, 2022). Moreover, agriculture provides livelihood for approximately 70% of impoverished individuals residing in rural areas worldwide. This sector's importance cannot be understated, especially when it comes to enhancing the economic prospects of sub-Saharan Africa, including Ghana (Kurgat *et al.*, 2020).

However, the agricultural sector faced considerable challenges, particularly concerning crop production. For instance, the demand for crop production is expected to increase by 60-70% to feed a projected global population of 9.8 billion by 2050 seriously challenged by climate change, which has emerged as a critical factor affecting agricultural productivity among smallholder maize and sorghum farmers in sub-Saharan Africa (Kurgat *et al.*, 2020; Ahmed, 2022). Climate change shows up in SSA through increased precipitation variability, frequent temperature extremes, and

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persistent droughts culminating in increased food insecurity. Altogether, an estimated 48 million people in the region may face acute food insecurity. UN/DESA, 2023.(UN/DESA, 2023).

Ghana is no exception since it is part of SSA. Evidence has shown that with annual crops declining by 40-50% due to climate change, 3.6 million Ghanaians, constituting 11.7% of the population are struggling to survive with low adoption capacity. Food insecurity in Ghana is high in the five northern regions: Upper East, 48.7%; North East, 33.0%; Northern Region, 30.7%; Upper West Region, 22.8%; and Savannah Region, 22.6%. This is a result of frequent drought and recurrent flooding in these regions (Stephen Asante, 2023). Efforts have been made towards combating climate change in Ghana, including commitments to cut emissions and enhance climate resilience by 2030, as outlined in the country's Nationally Determined Contributions. However, Zakaria et al (2021) note that the implementation of such initiatives remains inadequate. As a result, smallholder farmers, who are already the most affected by climate variability, continue to face heightened risks to their livelihoods and food security.

Farming activities in the regions of the north play a central role in sustaining food security and livelihoods (Issahaku and Abdulai, 2020). Smallholder farmers, who primarily grow staple cereals like maize and sorghum on small plots of land, typically less than two hectares, using family labour, and relying on rain-fed agriculture, face significant risks from climate-induced events such as droughts, floods, and heat stress (Ahmed, 2022). This underscores the need for climate-smart agricultural practices (CSAPs), which offer a strategic approach to enhance resilience, mitigate risks, and optimize productivity (Lipper *et al.*, 2018; Botchway *et al.*, 2016; Zougmoré *et al.*, 2021). The study adopted a transdisciplinary approach to comprehensively address the multifaceted challenges confronting the smallholder farmers in Northern Ghana The transdisciplinary method integrates knowledge from agriculture science, climate change studies, economics, and sociology and actively involves stakeholders such as farmers, policymakers, and agriculture experts (Pohl *et al.*, 2010). This approach is crucial for understanding the complex interplay between the environmental, social and economic factors that influence the adoption of CSAPs and the resilience of farming communities in regions of the north (Leventon *et al.*, 2016).

This study makes several unique contributions to the existing body of knowledge. First, it examines the adoption of CSAPs among smallholder maize and sorghum farmers in Northern Ghana, a region critical to Ghana's agricultural economy but underrepresented in research on climate-smart agriculture (Yaro, 2010). By exploring factors that influence the adoption of CSAPs, this study provides insights into the barriers and enablers that affect farmers' decisions, thereby contributing to a deeper understanding of climate-smart agriculture in the region. This focus on smallholder farmers adds a valuable perspective to the broader discourse on climate change adaptation in agriculture.

Second, the study's multivariate probit regression analysis allows for a critical examination of multiple factors influencing CSAP adoption, such as household characteristics, biosecurity, climate information, land ownership, market access, education, and marital status. By identifying these determinants, this study offers evidence-based recommendations for policymakers and practitioners seeking to promote CSAPs in similar contexts.
The chosen study locations in Northern Ghana—particularly in the Northern, Upper East, and Upper West regions—are representative of broader agricultural patterns in the area. These regions are significant for several reasons (MoFA, 2017).

First, these regions are central to Ghana's maize and sorghum production, with a high concentration of smallholder farmers reliant on these crops for their livelihoods. Second, climate Vulnerability. The Northern, Upper East, and Upper West regions are among the most affected by climate change in Ghana, with increasing temperatures, unpredictable rainfall patterns, and frequent droughts. This makes them ideal locations for studying the impact of climate-smart agriculture ( Botchway *et al.*, 2016; MoFA, 2017).

Finally, socioeconomic Diversity. The study locations encompass a diverse range of socioeconomic conditions, providing a comprehensive view of the factors influencing CSAP adoption. This diversity ensures that the study findings apply to a broader population of smallholder farmers in Northern Ghana (Bawayelaazaa Nyuor *et al.*, 2016). By focusing on these regions, this study not only addresses a critical gap in the literature but also provides valuable insights that can inform climate adaptation strategies in similar contexts.

### *1.1 Research Questions and Structure*

This study addresses two primary research questions:
What CSAPs are used by smallholder maize and sorghum farmers in Northern Ghana?

What are the determinants of climate-smart agricultural practices adopted by smallholder maize and sorghum farmers in Northern Ghana?

Climate-smart agriculture has increasingly become a linchpin for global food security (FAO, 2020; Zougmoré *et* *al.*, 2021; Raj *et al.*, 2022). Addressing this critical knowledge gap is imperative for tailoring sustainable interventions that not only elevate the livelihoods of smallholder farmers but also contribute to achieving the United Nations Sustainable Development Goals (SDGs). Specifically, this study aligns with SDG 1 (No Poverty) by addressing the persistent challenges of poverty and SDG 2 (Zero Hunger) through its focus on improving crop productivity and income. The subsequent sections of this paper detail the materials and methods of the study, present the study results, discuss the findings, and conclude with recommendations for policy and practice. The following sections detail the materials and methods of the study, present the study results, discuss the findings, and conclude with recommendations for policy and practice.

# 2. Materials and Methods

## *2.1 Research Design*

The study adopts a transdisciplinary research design, blending scientific inquiry with local knowledge to assess the Factors Influencing the Adoption of climate-smart agriculture among Maize and Sorghum Farmers in northern Ghana. The research focuses on co-producing knowledge through active collaboration between farmers, agricultural experts, policymakers, and development agencies.

The design incorporates qualitative, quantitative, and participatory approaches, allowing for a comprehensive understanding and selection of CSA practices. The transdisciplinary process involves stakeholders from the problem identification stage to implementing recommendations.

### *2.1.1 Stakeholder Involvement and Co-Production of Knowledge*

The key stakeholders who were engaged throughout the research process to ensure the integration of both academic and local perspectives: first, smallholder farmers. Local farmers contributed their practical insights and factors influencing their adoption of CSA practices adopted and used. These were based on their experiences. Second, local Agricultural Extension Officers. These officers offered technical knowledge and closed the gap between scientific research and local farming practices. Third, Agricultural Scientists and Economists. These were specialists who analyzed the CSA impacts on crop yield and household income. Policymakers and Development Practitioners. Representatives from government bodies. For instance, the Ministry of Agriculture and NGOs involved in CSA projects helped in shaping practical solutions. Stakeholders participated in the research process through, focus groups, and periodic feedback sessions to ensure that their experiences and needs were reflected in the findings.

## *2.2 Study area*

Agriculture primarily characterized the Upper West, Upper East and Northern Regions of Ghana, with farming as the predominant economic activity. These regions experience a single rainy season spanning May to October. The average minimum and maximum temperatures of the region are 14 °C at night and 40°C during the day. The region experiences two seasons: the dry season (November to April) and the wet season (May to October), with an average annual rainfall of 750–1050 mm (GSS, 2015). The dry season started in November and ended in March/April, characterized by the highest temperatures observed toward the end of this period (March-April), while December and January exhibited the lowest temperatures (GSS, 2015).

The occurrence of Harmattan winds from December to mid-February in the specified areas has significant implications for the local climate. Temperature variations between 14 °C at night and 40° Cduring the day, coupled with very low humidity, create challenging conditions with potential consequences for various sectors, including agriculture.

This is crucial, particularly in the context of food crop production. Extreme temperatures and low humidity associated with Harmattan winds can negatively impact crop growth and yield. Understanding and addressing these climatic challenges are essential for ensuring food security in affected regions (Adu and Asiamah, 2003).

## *2.3 Sampling and sample techniques*

The study used a multistage sampling technique to select participants from the population of smallholder farmers in three regions: the Northern Region, the Upper East Region, and the Upper West Region. This approach involved several stages of selection to ensure a representative sample from these diverse areas.

Stage 1: Region Selection

The first stage involved selecting three regions where the study would be conducted. These regions were chosen based on their significant population of smallholder farmers and geographic representation. The regions selected were the Northern, Upper East, and Upper West regions.

Stage 2: District Selection

Within each selected region, the study identified specific districts where the study would occur. The districts were selected purposively based on their agricultural activity, access to climate-smart agricultural practices, and accessibility for the research team. For example:

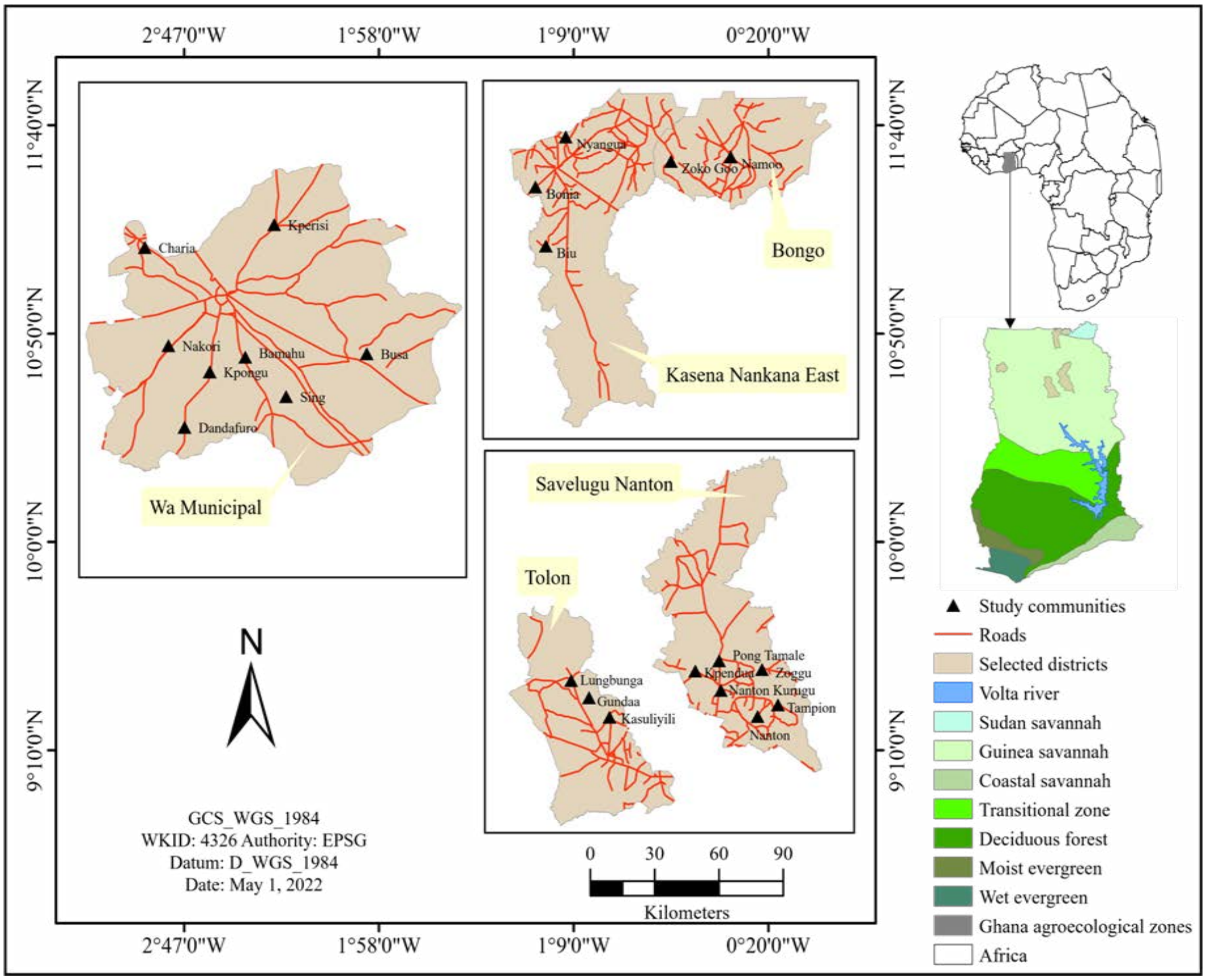


**Figure 1:** Map of the districts and communities where data were collected

In the Northern Region, the study chose the Savelugu and Tolon districts.
In the Upper East Region, the study chose the Bongo and Kasina-Nankana districts.
In the Upper West Region, the study chose the Wa West and Nadoli districts.

Stage 3: Community Selection

Within each selected district, the study further selected specific communities. This selection was also purposive, focusing on communities with a high density of smallholder farmers who had access to and used climate-smart agricultural practices. For example:
In the Savelugu district, the study selected the Nanton and Pong-Tamale communities.
In the Bongo district, the study selected the Namoo and Zoko Goo communities.
In the Wa West district, the study selected the Kpongu and Charia communities.

Stage 4: Participant Selection

Finally, the study selected individual smallholder farmers within each community. The selection was performed using a random sampling technique from a list of registered smallholder farmers maintained by the Ministry of Food and Agriculture (MoFA). The sample sizes for each community were proportionate to the population of smallholder farmers, ensuring balanced representation across regions and districts.

The total sample size for this study was 1,000, which was distributed across the three regions as follows:

Northern Region: 338 participants
Upper East Region: 330 participants
Upper West Region: 332 participants. The table summarizes how multistage sampling was conducted.

## 2.4 Methods of Data Analysis and Model Specification

## Participatory Methods

To ensure that the research is collaborative and reflective of local realities, the following participatory methods will be integrated:

**Participatory Rural Appraisal (PRA)**: Farmers will actively participate in mapping their farm systems, identifying key resources, and discussing climate risks. This will help highlight the role of CSA in addressing vulnerabilities in the farming systems.

**Stakeholder Workshops**: Regular workshops will bring together all stakeholders (farmers, policymakers, scientists) to co-interpret results and develop action plans. These workshops will serve as platforms for feedback and validation of findings.

The study used both qualitative and quantitative methods, with manual transcription chosen for its precision and accuracy in capturing responses from smallholder farmers. This method was chosen over automatic transcription, which offers speed but may vary in accuracy. Results are displayed using tables and figures.

## 2.5 Multivariate Probit Model

The multivariate probit model was used to estimate factors influencing climate-smart agriculture (CSA) practices which enhance agricultural productivity while minimizing environmental impact. Multiple interrelated variables in CSA, including mulching, chemical fertilizer application, agroforestry, conservation agriculture, intercropping and crop choice, were analyzed using the multivariate probit model to examine the determinants of adoption as well as correlation and interactions between alternatives (Aryal *et al.*, 2018).

The multivariate probit model allows researchers to account for the inherent interdependencies and correlations among the adoption decisions of different CSA practices. It provides insights into how various factors, such as socioeconomic variables, access to resources, climate conditions, and farmer characteristics, jointly influence the adoption of multiple CSA practices. The multivariate probit model aids researchers in understanding decision-making processes in CSA adoption, identifying factors affecting adoption likelihood, and enabling effective intervention and support mechanisms for sustainable agriculture (Aryal *et al.*, 2018).

## 2.5.1 Model Equation

The estimation process involves maximizing the likelihood function, which measures how well the model fits the observed data. The model can be specified as follows:

or

where denotes the farmers, and represents the outcomes or choices, is a -vector of exogenous covariates, the are assumed to be independent identically distributed across but uncorrelated across;

where Ω is the variance– covariance matrix. The off-diagonal elements in the correlation matrix represent the unobserved correlation between the stochastic component of *the eth* and *m*th options.

The error terms jointly follow a multivariate normal distribution (MVN) in this model with the option of using different CSA methods, with a zero conditional mean and variance adjusted to unity (Aryal *et al.*, 2018). Because a multivariate probit model can consider correlations between disturbance variables, it is preferable to separate univariate probit models when analyzing the adoption of many practices (Veronesi, 2013; Mulwa *et al.*, 2017).

2.5.2 Justification for Choosing the Multivariate Probit Regression:

The multivariate probit model is appropriate for analyzing the adoption of multiple CSA practices because they may not be independent of each other. There are several reasons for this. First, interdependencies. Farmers often adopt multiple practices simultaneously because of resource constraints, similar goals, or shared technologies. The multivariate probit model allows for the capture of these interdependencies. Second, correlated Error Terms: The error terms in the adoption of one practice could be related to those in another due to unobserved factors like farmer characteristics or local climate conditions. The multivariate probit model accounts for these correlations using a variance-covariance structure. Finally, joint Influence of Covariates: When examining factors influencing the adoption of multiple practices, the same covariates can affect each practice differently. The multivariate probit model can examine the joint influence of these covariates on multiple outcomes, thus providing a more comprehensive understanding of the adoption process.
2.5.3 Potential Biases and Limitations of the Multivariate Probit Model:

While the multivariate probit model has several advantages, it is important to recognize its limitations and potential biases. First, complexity and Computational Intensity. The multivariate probit model can be computationally intensive, especially when dealing with several choices or covariates. This complexity may affect the accuracy of the estimations and the time required to run the analyses. Second, identifyability Issues. When estimating the variance-covariance matrix, it can be challenging to ensure identifiability, especially with small sample sizes or when covariates are highly collinear. Third, model assumptions: The multivariate probit model assumes that the error terms follow a multivariate normal distribution with a mean of zero and a specified covariance structure. Any deviation from these assumptions can lead to biased results. Finally, the measurement error. If there is measurement error in the covariates or outcomes, it could lead to biased estimates. This model may be more sensitive to such errors because of the complexity of the relationships.

## 2.6 Data and description of the variables

### *2.6.1 Dependent variables*

The study strategically considered six crucial climate-smart agriculture (CSA) practices—namely, mulching, agroforestry, conservation agriculture, intercropping, crop diversity, chemical fertilizer application, and crop choice. Bell *et al.* ( 2018) underpinned the selection with prior assumptions, which posit that each identified practice has significant potential to contribute to one or more CSA goals. The unique challenges faced by Northern Ghana's agriculture, shaped by its dry, deciduous to semi-arid climate, high rainfall, and extreme weather events (Botchway *et al.*, 2016b), further informed the choice of these practices.

The pressing impact of climate change on agriculture and food systems in the region has manifested in low farm productivity, suboptimal husbandry practices, inadequate nutrient use, poor postharvest management, weak market linkages, and limited access to financing (Bawayelaazaa Nyuor *et al.*, 2016). Recognizing the imperative for comprehensive developmental approaches, this study aligns with the principles of climate-smart agriculture (CSA) to not only reduce greenhouse gas emissions but also enhance agricultural productivity and build resilience among smallholder farmers (Botchway *et al.*, 2016b). This commitment culminated in the official launch of adaptive strategies in Northern Ghana (Botchway *et al.*, 2016b; Zougmoré *et al.*, 2016)).

In addition, the study employs farmers' self-reported adoption responses yes/no to decipher the adoption landscape. Proxy indicators, including mulching, chemical fertilizer application, crop choice, intercropping, agroforestry and conservation agriculture, were used to assess household farm outcomes, specifically in terms of maize and sorghum yield and income. This is because the study adopted a cross-sectional research design and data were collected during one period. A number of studies such as (Teklewold *et al.*, 2013; Ndiritu *et al.*, 2014; Wainaina *et al.*, 2016; Mulwa *et al.*, 2017; Ogle *et al.*, 2018) have used crop and livestock indicators to denote diverse agricultural farming systems in SSA. Therefore, the interpretation and discussion of the study findings is limited to the number of practices and crop types at the time of data collection.

### 3.6.2 Definition of variables

Table 2 summarizes contextualized definitions of the variables used in this study. In all, there are 18 independent variables. Column one represents the variable name, and column two indicates the definition of the variable in the context of the study and how the variable is measured. Column three indicates the expected sign/direction of the variable in the various models and defines the a priori expectation.

**Table 2:** Definitions of variables

| Variable | Definition/measurement | Expected sign |
|---|---|---|
| Age | Total number of years of a farmer's life since birth | + |
| Sex | Dummy: sex of the household head (1 = male, 0 = female | + |
| Marriage | Dummy: 1 = for marriage, 0 = for single | + |
| Household size | Total number of people in the housing unit receiving food from the same source | +/- |
| Livelihood | Dummy: 1 for maize and sorghum farmers, 0 otherwise | |
| Land slope | categorical: one for flat land, 0 for steeper land slope | + |
| Extension | Total number of farmers who have access to extension officers' information | + |
| C. information | Farmers who access climate information | + |
| A. market | Farmers who have access to the market | + |
| Land tenure | Farmers with access to larger farmland | + |
| Hired labor cost (log) | Natural log of the total number of persons available who worked on the farmers' fields during the farming season | + |
| Phone | Dummy: 1 for farmers' access to the phone, 0 otherwise | + |
| Land size | Total area or measurement of a piece of land or real estate | + |

| | | |
|---|---|---|
| Education | Number of years spent in formal schooling | + |
| Maize output | Output per hectare (kg) | + |
| Sorghum yield | Output per hectare (kg) | + |
| Maize income | Output per hectare in Ghana cedis | + |
| Sorghum income | Output per hectare in Ghana cedis | + |

# 3. Results

## *3.1 Demographic characteristics*

The results of demographic characteristics for the maize and sorghum farmer adopters and non-adopters of the CSAPs are presented in Table 4.1. The average age of adopters and non-adopters of CSAPs was 38 and 37 years, respectively, which is significant at the 5% level. This indicates that age plays a role in distinguishing CSA adopters from non-adopters. The number of adopters and non-adopters of male-headed households was 72% and 75%, respectively, but there was no significant difference between adopters and non-adopters. The results revealed that adopters and non-adopters among married household heads were 82% and 81%, respectively. The average household size was 11 for both adopters and non-adopters, but there were no significant differences between the two groups. Biosecurity was found to be similar between adopters and non-adopters, with no significant differences.

The land slope was found to be 73% and 65%, respectively, for adopters and non-adopters at a 1% significance level. This indicates that adopters tend to have steeper land slopes than non-adopters. It was also revealed that 16% and 26% of adopters and non-adopters, respectively, had the service of extension officers. This implies that non-adopters were more likely to have access to such support. The results revealed that access to climate information was 53% and 36% for adopters and non-adopters, respectively, indicating that adopters were more likely to have access to this type of information. Access to the agriculture market was found to be 30% and 27% for adopters and on-adopters, respectively, indicating that adopters had a slightly higher level of access. The results found that land tenure was 45% and 61% for adopters and non-adopters, respectively, at 1 % significance level. This indicates that non-adopters were more likely to have secure land tenure than adopters.

Furthermore, the cost of hiring labour was 3.857 and 4.229 for maize and sorghum for adopters and adopters, respectively, at 10% significance level. This demonstrates that non-adopters typically face higher labour costs than adopters. Access to a phone was found to be between 43% and 39% for adopters and non-adopters, but there was no significant difference between adopters and non-adopters. This implies that both adopters and non-adopters in this context have relatively similar access to this technology.

The results showed that land size was 3.427 hectares and 4.077 hectares for adopters and non-adopters, respectively, at 1% significance. This supports the idea that non-adopters typically have larger land holdings than adopters. Educational level was found to be 8.031 and 8.554 at 1% significance level for adopters and non-adopters, respectively. The data support the notion that non-adopters tend to have slightly higher educational levels than adopters.

The Maize output for aadopters was, on average 1600kg/ha, while non-adopters was 1300kg/ha. This means adopters have a higher maize yield of 300 kg/ha. The difference of -2.4966 is statistically significant at a high confidence level, as indicated by the three asterisks (***). On the other hand, the income of aadopters earns 3,200 GH₵from maize, whereas non-adopters earn 2,600 GH₵. This is after all consumables. Therefore, adopters earn 600 GH₵ more from maize than non-adopters. However, the difference in income is not statistically significant, suggesting that there is variability in the income data.

The output of aadopters for sorghum was on average 1300 kg/ha, compared to 1.10 kg/ha for non-adopters. This indicates that adopters have a slightly higher sorghum yield of 200 kg/ha. The difference of 163 kg/ha is not statistically significant. The income of aadopters was 2,600 GH₵ from sorghum, while non-adopters earn 2,200 GH₵. Thus, adopters earn 400 GH₵more from sorghum than non-adopters. This difference in income is also not statistically significant.

The total output for aadopters of maize and sorghum was 2900 kg/ha, compared to 2400 kg/ha for non-adopters. Adopters have a higher total yield of 500 kg/ha. The difference of -2.1499 is statistically significant. Total Income: Adopters earn a total income of 5,800 GH₵, while non-adopters earn 4,800 GH₵. Adopters' total income is 1,000 GH₵ more than that of non-adopters. However, this difference in total income is not statistically significant, indicating variability in income.

**Table 4.1:** Demographic characteristics of sampled smallholder maize and sorghum farmers

| Variable | CSA adopters | CSA non-adopters | t-test/chi2 | Pooled |
|---|---|---|---|---|
| Age | 38.42 | 36.75 | -2.2467** | 37.836 |
| Sex | 0.717 | 0.746 | 0.9743 | 0.727 |
| Marriage | 0.818 | 0.811 | -0.2735 | 0.816 |
| Household size | 11.170 | 11.19 | -1.3889 | 11.52 |
| Biosecurity | 0.951 | 0.949 | -0.1520 | 0.950 |
| Land slope | 0.729 | 0.651 | -2.5716*** | 0.702 |
| Extension | 0.163 | 0.263 | 3.800*** | 0.198 |
| C. information | 0.532 | 0.366 | -5.0922*** | 0.474 |
| A. market | 0.295 | 0.269 | -0.8944 | 0.286 |
| Land tenure | 0.452 | 0.606 | 4.6737*** | 0.506 |
| Hired labour cost (log) | 3.857 | 4.229 | 1.6756* | 3.988 |
| Phone | 0.425 | 0.389 | -1.1041 | 0.412 |
| Land size | 4.066 | 3.427 | -3.3943*** | 3.859 |
| Education | 8.031 | 8.554 | 2.9518*** | 8.214 |
| Maize output (kg/ha) | 9.963 | 9.9147 | -2.4966*** | 9.677 |
| Maize income (GH₵ | 1174.923 | 1104.857 | -0.8719 | 1150.40 |
| Sorghum yield (kg/ha) | 3.009 | 3.030 | 0.1631 | 3.017 |
| Sorghum income (GH₵ | 218.939 | 261.200 | 0.9775 | 233.73 |
| Total yield (kg/ha) | 12.972 | 12.177 | -2.1499*** | 12.694 |
| Total income (GH₵) | 1393.862 | 1366.057 | -0.2812 | 1384.13 |

Source: Field data estimate using STATA, 2022.

## 3.2 Adoption Status of Climate-Smart Agriculture Practices

Table 4 presents the adoption of the CSA practice status by smallholder maize and sorghum farmers in Northern Ghana. Approximately 8% of maize farmers adopted mulching, whereas 10 % of sorghum farmers adopted mulching. The combined adoption of mulching was 9%. This indicates that smallholder farmers had an unfavourable climate, resource scarcity, limited knowledge, and cultural preferences regarding this practice.

Adopters of agroforestry for maize farmers were 3%, sorghum was 2%, and pollen was 1%. This means that smallholder farmers have no interest in integrating agroforestry practices into their farming practices. Furthermore, it was found that 59% of the maize farmers adopted chemical fertilizer, while 10% of the sorghum farmers adopted chemical fertilizer. The combined adoption of chemical fertilizer was 56%. Furthermore, almost half 49% of the maize and sorghum farmers adopted conservation agriculture. The combined adoption rate was 40%. This indicates that some farmers do not fully embrace or implement conservation agriculture approaches, possibly because of the limited knowledge or resources required for such practices.

The adoption rate of crop diversity for maize farmers was found to be 36%, while that of sorghum farmers was 38%, which was slightly higher than that of maize farmers. The combined adoption rate was 25%. This indicates that sorghum farmers may have a relatively greater inclination toward diversifying their crops than maize farmers in the region. Approximately 39% of maize farmers adopted intercropping, whereas 43% of sorghum farmers adopted intercropping. This indicated that sorghum farmers may have found intercropping to be a more suitable and beneficial practice for their specific crop. Finally, 27% of maize and sorghum farmers adopted a crop choice, whereas the combined adoption rate was 14%. This indicates that many farmers in the region may not be actively selecting crops based on market demand.

Source: Field data estimate using STATA, 2022

## 3.3 Adoption of CSA practices based on location

This section examines the CSAPs used by smallholder maize and sorghum farmers based on their location. The popular CSA practices in the Northern, Upper East, and Upper West regions of Ghana are shown in Figure 3.

In the preceding growing seasons, CSA practices were widely adopted by households across all three regions. Chemical fertilizer application stood out as the predominant practice in the Northern Region, with a usage rate of 72%, followed closely by the Upper West Region at 51%. Conversely, in the Upper East Region, smallholder farmers demonstrated a higher preference for conservation agriculture (CA), with a usage rate of 56%. Notably, among maize and sorghum smallholder farmers, crop choice, mulching, and agroforestry. emerged as the least used CSA methods in these regio

Table 4: Descriptive Statistics: Adoption Rates of Climate-Smart Agriculture Practices for Maize, Sorghum, and Pooled Data

| CSA | Maize | | Sorghum | | Pooled data | |
|---|---|---|---|---|---|---|
| | | Std. Dev. | Freq. (%) | Std. Dev. | Freq. (%) | Std. Dev. |
| Mulching | 7.80 | 0.268 | 9.80 | 0.297 | 8.60 | 0.281 |
| Agroforestry | 2.80 | 0.165 | 1.60 | 0.126 | 1.20 | 0.109 |
| C. fertilizer | 59.20 | 0.492 | 46.00 | 0.499 | 55.80 | 0.497 |
| CA | 48.60 | 0.500 | 48.60 | 0.500 | 39.80 | 0.489 |
| Crop diversity | 36.0 | 0.480 | 38.40 | 0.487 | 25.0 | 0.433 |
| Intercropping | 39.00 | 0.488 | 42.80 | 0.495 | 32.40 | 0.468 |
| Crop choice | 27.20 | 0.445 | 26.80 | 0.443 | 14.20 | 0.349 |

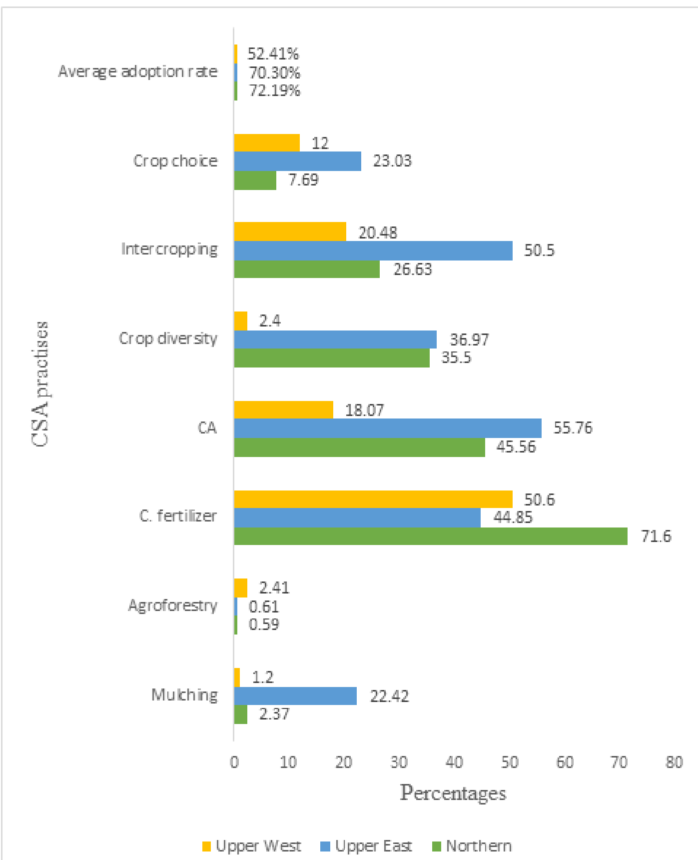


Figure 2: Use of CSA practices by smallholder farmers in the Northern, Upper East, and Upper West regions of Ghana

## *3.4 Determinants of climate-smart agricultural adoption*

Table 5 presents the results of the determinants of CSA practices by individual adoption in the study area. The Wald Chi$^2$ value is 739.08, which is significant at 1 %. The likelihood ratio test (chi$^2$ = 695.668 and Prob > chi$^2$ = 0.0000) was also significant. This model diagnosis justifies the use of a multivariate probit model.

Sex was found to have a significant negative effect on chemical fertilizer at 10 %. This implies that female-headed households are more likely to adopt chemical fertilizers than male-headed households. The study also found that marriage had a significantly negative effect on mulching adoption at 10 %, but a significant positive effect on crop diversity and intercropping adoption at 5 %. These findings indicate that married farmers are less likely to adopt mulching but more likely to adopt crop diversity and intercropping. The study further found that household size had a significant positive effect on the adoption of CA and crop choice at 1% and %, respectively. This indicated that larger households may have more labour resources available, making it easier for them to implement CA practices and choose a wider variety of crops. The study indicated that biosecurity had a significant negative effect on the adoption of mulching at 1% and a significant positive effect on intercropping and crop choice at 5% and 5%, respectively. This means that higher biosecurity helps reduce the risk of crop damage caused by pests and diseases.

The land slope was found to have a positive and significant effect on the adoption of mulching at 5%, whereas it had a negative significant effect on crop choice at 5%. This means that farmers may adopt mulching to prevent soil erosion and conserve moisture while negatively affecting crop choice due to constraints in planting and uneven terrain management. The study further revealed that extension services had a significant negative effect on the adoption of chemical fertilizer at 5%. This implies that the availability or quality of extension services in the area may not effectively promote or encourage the use of chemical fertilizers among farmers. In addition, climate information was found to have a significant positive effect on the adoption of chemical fertilizer, CA, intercropping, crop choice and crop diversity at 1% and 5% significance levels, respectively. This indicates that access to climate information may enable farmers to make more informed and adaptive decisions about their agricultural practices.

The study indicated that access to the agricultural market had a positive and significant effect on the adoption of mulching, intercropping, and crop choice at 1% and 10%, respectively. A significant negative effect on the adoption of crop diversity was observed at the 1% significance level in the study, indicating that external factors, such as limited access to resources or unfavourable environmental conditions, may hinder farmers' willingness to embrace a wider range of crops in their cultivation practices. This implies that farmers with market access are more likely to adopt market-oriented practices. Land tenure had a positive and significant effect on the adoption of crop choice at the 5% level. Conversely, our findings revealed significant negative effects on the adoption of chemical fertilizer, conservation agriculture (CA), intercropping, and crop diversity at 1% and 10%, respectively, indicating potential barriers or challenges associated with these practices in the studied agricultural context. This may mean that secure land tenure encourages crop choice but discourages the adoption of chemical fertilizer, CA, intercropping and crop diversity due to investment risk.

The study discovered that household labour costs had a negative and significant effect on the adoption of crop diversity at 10 %. This indicates that higher household labour costs may discourage farmers from adopting crop diversity practices because of the increased labour demands associated with managing various crops. At the 10% significance level, phone access had a negative significant effect on CA adoption. Access to a phone may reduce the perceived need for adopting CA practices because it provides an alternative means of accessing agricultural information and resources, potentially leading to lower adoption rates. The study further indicated that land size had a positive significant effect on the adoption of mulching, chemical fertilizer and CA at 1 % and 5 %, respectively, while a negative significant effect on the adoption of crop choice was at the 5% significance level. This may mean that larger land sizes encourage the adoption of multiple practices such as mulching, chemical fertilizer and CA due to the potential for increased yields, but discourage crop choice as larger farms may require more focused management.

Educational level had a significant positive effect on the adoption of intercropping and crop choice at 10 % and 5 %, respectively, while a significant negative effect on the adoption of crop diversity was found at 1 %. This implies that higher education levels promote intercropping and crop choice by enhancing knowledge and decision-making skills, but may discourage crop diversity as more educated farmers focus on fewer, potentially more profitable crops.

Location (Northern Region) had a significant positive effect on the adoption of chemical fertilizer at 1 % compared with the Upper East Region, whereas a significant negative effect was found on the adoption of mulching, CA, intercropping and crop choice at 1 %. This indicates that the location (Northern Region) may have specific soil and climatic conditions that favour chemical fertilizer use but discourage the adoption of mulching, CA, intercropping and crop choice due to regional constraints and practices. The study revealed that Upper West (location) had a significant negative effect on the adoption of mulching, CA, intercropping, and crop choice at 1 % and 10 % significance levels, respectively. The unfavourable conditions or practices of the Upper West may deter the adoption of mulching, CA, intercropping, and crop choice, leading to significant negative effects. Perhaps due to the harsh climatic conditions prevalent in the region, which is characterized by arid or semi-arid environments and erratic rainfall patterns.

**Table 5:** Determinants of CSA using the multivariate probit regression approach

| Variables | Mulching (1) | C. fertilizer (2) | CA (3) | Crop diversity (4) | Intercropping (5) | Crop choice (6) |
|---|---|---|---|---|---|---|
| Age | -0.00212 | 0.00421 | 0.000833 | 0.00258 | 0.00689 | 0.00341 |
| | (0.00696) | (0.00453) | (0.00425) | (0.00474) | (0.00438) | (0.00514) |
| Sex | 0.0583 | -0.175* | -0.0566 | -0.000700 | -0.0546 | 0.0533 |
| | (0.167) | (0.0953) | (0.0938) | (0.108) | (0.0955) | (0.117) |
| Marriage | -0.317* | -0.0751 | 0.169 | 0.304** | 0.235** | -0.0221 |
| | (0.190) | (0.116) | (0.113) | (0.129) | (0.116) | (0.133) |
| Household Size | 0.00708 | 0.00636 | 0.0276*** | 0.0105 | -0.00570 | 0.0224** |
| | (0.0147) | (0.00822) | (0.00771) | (0.00868) | (0.00798) | (0.00928) |
| Biosecurity | -0.935*** | -0.292 | 0.0704 | -0.0417 | 0.655** | 0.736** |
| | (0.256) | (0.203) | (0.191) | (0.218) | (0.298) | (0.343) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Land slope | 0.370** | 0.103 | -0.0607 | -0.0724 | -0.147 | -0.266** |
| | (0.165) | (0.0934) | (0.0933) | (0.108) | (0.0949) | (0.110) |
| Extension | -0.299 | -0.241** | 0.0261 | -0.196 | -0.0868 | -0.186 |
| | (0.210) | (0.110) | (0.113) | (0.148) | (0.115) | (0.141) |
| C. information | -0.0578 | 0.340*** | 0.336*** | 0.232** | 0.484*** | 0.562*** |
| | (0.159) | (0.0919) | (0.0916) | (0.111) | (0.0936) | (0.120) |
| A. market | 0.499*** | -0.0340 | 0.0487 | -0.466*** | 0.402*** | 0.199* |
| | (0.163) | (0.104) | (0.0988) | (0.123) | (0.0980) | (0.119) |
| Land tenure | 0.164 | -0.359*** | -0.245*** | -0.170* | -0.318*** | 0.218** |
| | (0.155) | (0.0887) | (0.0866) | (0.101) | (0.0885) | (0.110) |
| H. Labor cost | 0.0230 | 0.00886 | -0.00316 | -0.0286* | -0.00772 | -0.0121 |
| | (0.0220) | (0.0130) | (0.0127) | (0.0148) | (0.0128) | (0.0162) |
| Phone | -0.220 | -0.0953 | -0.151* | 0.0197 | 0.0184 | 0.0122 |
| | (0.157) | (0.0908) | (0.0895) | (0.102) | (0.0895) | (0.110) |
| Land size | 0.165*** | 0.200*** | 0.0557** | 0.0303 | 0.0243 | -0.0839** |
| | (0.0438) | (0.0294) | (0.0271) | (0.0310) | (0.0268) | (0.0343) |
| Education | 0.0167 | -0.0255 | 0.00457 | -0.0561*** | 0.0282* | 0.0522** |
| | (0.0250) | (0.0166) | (0.0161) | (0.0186) | (0.0160) | (0.0208) |
| Northern | -1.536*** | 0.544*** | -0.349*** | -0.0898 | -0.631*** | -0.442*** |
| | (0.203) | (0.119) | (0.112) | (0.121) | (0.117) | (0.149) |
| Upper West | -1.743*** | -0.0350 | -1.173*** | -1.711*** | -0.714*** | -0.242* |
| | (0.246) | (0.113) | (0.120) | (0.184) | (0.116) | (0.140) |
| Constant | -0.573 | -0.0801 | -0.505 | -0.128 | -1.168*** | -2.523*** |
| | (0.529) | (0.352) | (0.342) | (0.386) | (0.353) | (0.517) |
| Model diagnosis | | | | | | |
| Wald chi2(96) | 739.08 | | | | | |
| Prob > chi2 | 0.0000 | | | | | |
| Log likelihood | -2400.6898 | | | | | |
| Observations | 1,000 | | | | | |

Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho32 = rho42 = rho52 = rho62 = rho43 = rho53 = rho63 = rho54 = rho64 > = rho65 = 0: chi2(15) = 695.668 Prob > chi2 = 0.0000

Noted: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1
Source: Field data estimates using STATA, 2022.

### *3.4.1 Correlation of adoption between CSA practices among maize and sorghum farmers*

Table 4.4 presents the inherent smallholder maize and sorghum farmers' adoption of multiple CSA practices for yield and income. The likelihood ratio test for maize was chi2 (15) = 1335.06 Prob > chi2 = 0.0000, whereas that for sorghum was chi2 (15) = 1216.74 Prob > chi2 = 0.0000, and the pooled was chi2 (15) = 695.668 Prob > chi2 = 0.0000, all at the 1% significance level. The data indicated that 1 = mulching, 2 = C. fertilizer, 3 = CA, 4 = crop diversity, 5 = intercropping and 6 = crop choice. The results of this study indicated that the CSA practices examined demonstrated a positive correlation and provided a synergistic effect. This indicates that farmers appear to adopt the two together, possibly because of synergies or complementary benefits. This study shows that the adoption of one climate-smart agriculture method augmented the adoption of the other. For instance, there was a significant positive coefficient of 0.219 (p = 0.001) for maize and 0.403 (p = 0.000) for C. Fertilizer and Mulching means a synergistic effect of chemical fertilizers and mulching on both crops. Again, maize showed a positive coefficient of 0.156 (p = 0.037), whereas sorghum exhibited a more substantial coefficient of 0.425 (p = 0.000), indicating a significant positive interaction between Conservation

Agriculture (CA) and mulching.

There is a positive coefficient of 0.172 (p = 0.018) for maize and 0.410 (p = 0.000) for sorghum, which signifies a favourable relationship between crop diversity and mulching, although the effect is more pronounced for sorghum. The results indicate that maize shows a non-significant coefficient (p = 0.383), whereas sorghum demonstrates a significant positive interaction (0.422, p = 0.022), meaning that mulching is more impactful when combined with intercropping for sorghum. Both maize and sorghum exhibit significant positive coefficients (maize: 0.197, p = 0.003; sorghum: 0.344, p = 0.000), indicating that the choice of crops alongside mulching positively influences yields.

There was a positive and significant coefficient across different combinations, indicating that the correlation of Conservation Agriculture (CA), chemical fertilizers, and crop diversity has a substantial positive impact on both maize and sorghum yields. Therefore, the likelihood ratio tests provide statistical evidence supporting the validity of the multivariate probit model, indicating that the estimated relationships are significant.

**Table 4.4:** Correlation coefficient of CSA practices (estimation from multivariate probit model)

| Interactions between CSA practices | Maize | | | Sorghum | | | Pooled | | |
|---|---|---|---|---|---|---|---|---|---|
| | Coefficient | Std. err | P>z | Coefficient | Std. err | P>z | Coefficient | Std. err | P>z |
| C. fertilizer and mulching | 0.219*** | 0.067 | 0.001 | 0.403*** | 0.063 | 0.000 | 0.348*** | 0.066 | 0.000 |
| CA and Mulching | 0.156** | 0.075 | 0.037 | 0.425*** | 0.059 | 0.000 | 0.256*** | 0.065 | 0.000 |
| Crop diversity and mulching | 0.172** | 0.072 | 0.018 | 0.410*** | 0.063 | 0.000 | 0.117 | 0.075 | 0.119 |
| Intercropping and Mulching | 0.064 | 0.074 | 0.383 | 0.422*** | 0.058 | 0.000 | 0.152** | 0.066 | 0.022 |
| Crop choice and mulching | 0.197*** | 0.067 | 0.003 | 0.344*** | 0.059 | 0.000 | 0.239*** | 0.071 | 0.001 |
| CA and C fertilizers | 0.857*** | 0.022 | 0.000 | 0.632*** | 0.040 | 0.000 | 0.724*** | 0.033 | 0.000 |
| Crop diversity and C fertilizer | 0.711*** | 0.034 | 0.000 | 0.615*** | 0.043 | 0.000 | 0.472*** | 0.051 | 0.000 |
| Intercropping and C. fertilizer | 0.777*** | 0.025 | 0.000 | 0.683*** | 0.033 | 0.000 | 0.618*** | 0.038 | 0.000 |
| Crop choice and C. fertilizer | 0.837*** | 0.029 | 0.000 | 0.493*** | 0.049 | 0.000 | 0.580*** | 0.050 | 0.000 |
| Crop diversity and CA | 0.635*** | 0.039 | 0.000 | 0.731*** | 0.034 | 0.000 | 0.461*** | 0.049 | 0.000 |
| Intercropping and CA | 0.832*** | 0.023 | 0.000 | 0.851*** | 0.021 | 0.000 | 0.717*** | 0.034 | 0.000 |
| Crop choice and CA | 0.818*** | 0.027 | 0.000 | 0.781*** | 0.029 | 0.000 | 0.502*** | 0.052 | 0.000 |
| Intercropping and Crop diversity | 0.599*** | 0.040 | 0.000 | 0.717*** | 0.033 | 0.000 | 0.558*** | 0.045 | 0.000 |
| Crop choice and diversity | 0.686*** | 0.039 | 0.000 | 0.730*** | 0.033 | 0.000 | 0.408*** | 0.059 | 0.000 |
| Crop choice and intercropping | 0.778*** | 0.029 | 0.000 | 0.830*** | 0.025 | 0.000 | 0.510*** | 0.050 | 0.000 |
| Diagnosis test | Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho32 = rho42 = rho52 = rho62 = rho43 = rho53 = rho63 = rho54 = rho64 = rho65 = 0: chi2(15) = 1335.06 Prob > chi2 = 0.0000 | | | Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho32 = rho42 = rho52 = rho62 = rho43 = rho53 = rho63 = rho54 = rho64 > = rho65 = 0: chi2(15) = 1216.74 Prob > chi2 = 0.0000 | | | Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho32 = rho42 = rho52 = rho62 = rho43 = rho53 = rho63 = rho54 = rho64 > = rho65 = 0: chi2(15) = 695.668 Prob > chi2 = 0.0000 | | |

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1 Source: Field data estimates using STATA, 2022.

# 4. Discussion

### *Sociodemographic characteristics of smallholder farmers and their correlation with CSAP adoption*

The study revealed a strong association between younger age and the adoption of CSA practices in the Northern, Upper East, and Upper West regions, meaning that these areas may become focal points for the spread of CSA. Younger farmers' inclination toward new practices aligns with global trends, where younger generations are more receptive to adopting sustainable practices. This can drive increased productivity and food security in the region, contributing to broader sustainability goals. This confirmed Azumah *et al.* (2017) findings that the average farming age in Northern Ghana is 37 years, possibly due to the high cost of grains attracting young people into farming businesses.

While the study reveals moderate educational levels among smallholder farmers, it highlights the positive correlation between education and climate change adaptation. This finding is consistent with global trends indicating that education plays a crucial role in CSA promotion. However, resistance to agricultural innovations among educated elites, as noted by Onyeneke *et al.* (2011), underscores the need for targeted initiatives that address uncertainties and build confidence in CSA practices. This is an opportunity for policymakers and development agencies to design educational programs and campaigns that emphasize the benefits of CSA.

The significant impact of household size on agricultural output in Northern Ghana emphasizes the importance of family labour in smallholder farming. This finding aligns with regional trends where family-based labour remains a critical resource for agricultural productivity. As the CSA movement gains traction globally, recognizing the role of household dynamics can guide the development of interventions that leverage family labour while promoting sustainable practices (Alhassan *et al.*, 2018).

The study's findings regarding the positive influence of farmland topography on climate change adoption in Northern Ghana contribute to the broader understanding of CSA. Flat farmlands that retain more water promote sustainable agricultural practices. This aligns with global trends emphasizing the importance of land management and soil conservation in climate-smart agriculture (Alhassan *et al.* (2018).

## *4.1 Adoption of climate-smart agricultural practices based on location*

This section examines the CSA practices used by smallholder maize and sorghum farmers based on location. The popular CSA practices in the Northern, Upper East, and Upper West regions of Ghana are shown in Figure 4. The study results showed that, overall, approximately half of the farmers adopted one or more or a combination of CSA practices to cope with changing climate and weather variability. The major adoption of CSA practices includes chemical fertilizer conservation agriculture, intercropping, crop choice and mulching. These findings are significant in highlighting the adaptive strategies that smallholder farmers are using to respond to climate variability, while also aligning with global efforts to address climate change in agriculture.

Chemical fertilizer use among smallholder farmers has become a common strategy to enhance crop yields in response to climate-induced challenges. This trend reflects broader patterns across Sub-Saharan Africa, where soil nutrient depletion and unpredictable weather patterns drive the increased use of chemical inputs (Kurgat *et al.*, 2020). However, concerns about the long-term sustainability of heavy fertilizer use, including soil degradation, water contamination and health risks for farmworkers, indicates a need to reconsider this approach. This calls for a balanced strategy that incorporates sustainable practices alongside chemical fertilizer use to ensure long-term viability.(Alhassan *et al.*, 2018; Amikuzuno and Donko, 2012).

Chemical fertilizers were initially used in Northern Ghana for soil improvement, but their widespread use raises concerns about health and long-term sustainability. Potential health risks from improper use, including acute toxicity and chronic health issues, necessitate a re-evaluation of agricultural practices to ensure the long-term well-being of farmworkers and communities (Feyisa, 2022).

The adoption of conservation agriculture (CA) by smallholder farmers in these regions demonstrates a shift toward sustainable farming practices. CA's benefits—such as improved soil health, reduced erosion, and water conservation, emphasize the importance of sustainable land management. This practice is part of a broader movement toward climate-smart agriculture, which promotes resilience and sustainability despite climate change. The findings of this study mean that CA can play a critical role in mitigating climate impacts while supporting food security and agricultural livelihoods (Hobbs, 2007; Stockman *et al.*, 2013; Smith, 2020).

Intercropping, as a popular CSA practice in Mozambique, has gained traction among smallholder farmers because of its ability to optimize land use, control diseases, and improve soil fertility. The results of this study indicate that intercropping can be a viable strategy for smallholder farmers in Northern Ghana, offering a flexible and resilient approach to farming despite climate uncertainty (Osman *et al.*, 2011; Ouédraogo *et al.*, 2019). This trend aligns with broader regional and global movements toward diversified and sustainable farming systems, which are key to enhancing resilience against climate-related shocks.(Osman *et al.*, 2011; Ouédraogo *et al.*, 2019).

A study on Northern Ghana's smallholder maize and sorghum farmers shows that nearly half have adopted climate-smart agriculture practices (CSAPs) to combat climate change impacts. These practices include chemical fertilizer conservation agriculture and intercropping, which enhance crop production, address soil degradation and ensure food security.

## *4.2 Determinants of climate-smart Agricultural Practice Adoption*

This section examines factors influencing smallholder maize and sorghum farmers' decisions to adopt climate-smart agriculture practices using multivariate probit regression models, considering six options with "no adoption" as the reference.

The study shows that larger households tend to adopt conservation agriculture and crop diversification strategies to enhance productivity and ensure food security. This finding is consistent with broader trends in Sub-Saharan Africa, where large households often serve as a source of agricultural labour, promoting resilience and flexibility in farming operations. The broader implication is that promoting conservation agriculture and crop diversity could benefit from policies that consider household dynamics and labour availability, reinforcing the importance of CSA in supporting sustainable livelihoods (Aryal *et al.* (2018) and Ojoko *et al.* (2017).

The positive correlation among biosecurity, intercropping, and crop choice indicates that adopting higher biosecurity levels leads to more robust pest and disease management. This trend aligns with global initiatives aimed at promoting sustainable agricultural practices that minimize pesticide use and support biodiversity. The broader implication here is the importance of biosecurity measures in reducing chemical dependence and promoting more ecologically sound farming practices, contributing to global efforts to reduce agricultural pollution and maintain ecosystem health. This is consistent with Maria *et al.* (2005), who found that higher biosecurity levels lead to the adoption of intercropping and crop choices.
Climate information plays a critical role in the adoption of chemical fertilizers, conservation agriculture, intercropping, and crop choice. This finding emphasizes the importance of accurate and timely climate information for smallholder farmers to optimize agricultural activities and mitigate risks. The broader trend in climate-smart agriculture involves leveraging technology and data-driven insights to improve decision-making in farming (Mulwa *et al.*, 2017; Ouédraogo *et al.*, 2019; Abegunde *et al.*( 2019)"type":"article-journal","volume":"16"},"uris":["http://www.mendeley.com/documents/?uuid=e12b9b1e-1b92-466d-bd50-8ecf7fb704cf"]},{"id":"ITEM-2","itemData":{"DOI":"10.3390/su12010195","ISSN":"2071-1050","abstract":"Agriculture, particularly small-scale farming, is both a contributor to greenhouse gas (GHG. The implication is that expanding access to climate information can drive the adoption of CSAPs, supporting global efforts to build climate-resilient agricultural systems.

The study reveals that household land size significantly influences the adoption of chemical fertilizers and crop diversity among maize and sorghum farmers. Larger landowners are more likely to adopt these practices, whereas those with rented land are less likely. This aligns with previous research on sustainable agricultural practices in Africa (Teklewold *et al.*, 2013). These findings concur with those of Darkwah *et al.* (2019) and Workineh *et al.*(2020), who found that smallholder farmers benefit from chemical fertilizer application and crop diversity trade-offs, with household size positively correlated with CSA practices. Furthermore, many studies have found a positive correlation between household size and CSA practices (De Falco *et al.*, 2014; Issahaku and Abdulai, 2020).

This study emphasizes the role of agricultural market access in promoting chemical fertilizer use, conservation agriculture, and crop choice, thereby enhancing productivity and yield, as supported by previous studies. The findings of this study have affirmed the results of many studies (Kassam *et al.*, 2010; Rosenstock *et al.*, 2019; Sadat Darakeh *et al.*, 2021) that reported that access to the agricultural market correlates with the adoption of improved agricultural practices such as CSA.

The findings of the study revealed that the educational level of smallholder farmers has played a decisive role in determining the adoption of crop choice. Ojoko *et al.* (2017) and Solís *et al.* (2007) found that higher education empowers farmers to make informed decisions about crop cultivation, adapt to changing conditions, and adopt advanced agricultural practices. This finding is consistent with global trends that emphasize the role of education in advancing sustainable agriculture. The implication is that educational initiatives can play a pivotal role in promoting CSA adoption, fostering a new generation of farmers equipped to address climate challenges and ensure food security.
Marital status significantly influences smallholder maize and sorghum farmers' crop choice labour availability, resource sharing and decision-making processes, thus contributing to climate-smart practices and sustainable farming systems in Southeast Nigeria. These findings are supported by Onyeneke *et al.* (2018), who illustrated that marital status affects labour availability, resource sharing and decision-making processes, contributing to climate-smart agricultural practices and sustainable farming systems in Southeast Nigeria.

The Northern Region's smallholder farmers are more likely to adopt chemical fertilizers because of factors such as soil fertility, crop patterns, awareness, market access, government policies, climate and peer influence, confirming previous research.

### *4.2.1 Compliment of Climate-Smart Agricultural Practices on Maize and Sorghum*

The results of this study revealed an inherently smallholder maize and sorghum farmer's adoption of multiple CSA practices for yields and income from maize and sorghum. The results indicated that all CSA practices in the study provided only a synergistic effect or commentary or positive correlation. This implies that the combination of the practices in the study appears to be complementary. These findings are consistent with those of Mutenje *et al.* (2016), who reported a correlation between sustainable intensification practices among smallholder farmers in Kenya. The complementary nature of CSA practices could be attributed to the desire among smallholder farmers to improve agricultural crop yield, adapt to climate change, and enhance income and food security (Mulwa *et al.*, 2017). In other words, the adoption of one climate-smart agriculture (CSA) practice tends to be positively correlated with the adoption of other CSA practices, indicating that farmers who adopt one practice are more likely to adopt multiple practices simultaneously. This indicates a coordinated and holistic approach to CSA adoption, which can lead to more sustainable and resilient agricultural systems. This indicated the appropriateness of the MVP model for determining the adoption of CSA practices among smallholder maize and sorghum farmers. The findings agree with those of Ahmed, (2022), Azumah *et al.* (2022), and Feyisa (2022), who showed MVP as an appropriate and effective model for determining the adoption of sustainable agriculture practices among smallholder farmers.

## 5. Conclusion

This study focused on the adoption of climate-smart agricultural practices (CSAPs) among smallholder farmers in the Northern Regions of Ghana, with an emphasis on maize and sorghum cultivation. The aim of this study was to identify the range of CSAPs adopted by farmers and examine the key factors influencing their decisions. The overarching objective was to provide insights that could guide policy and practical measures to support smallholder farmers in adapting to climate change while fostering sustainable and resilient agricultural systems.

Conservation agriculture and intercropping emerged as the second and third most popular CSAPs, respectively. This is an encouraging trend because these practices offer a range of benefits, including increased yield, improved soil fertility, reduced soil erosion, and better soil structure. These results support the notion that smallholder farmers are beginning to embrace more sustainable agricultural practices, which aligns with the broader objectives of climate-smart agriculture.

The second objective of this study was to identify the factors that influence the adoption of CSAPs. This study found that a combination of socioeconomic, environmental, and institutional factors played significant roles in shaping farmers' decisions. Key determinants included farmer age, marital status, household size, land slope, climate information, access to agricultural markets, land tenure, and geographic location. These factors provide a comprehensive understanding of the complexities surrounding CSAP adoption and provide valuable insights for policymakers and agricultural extension services.

## 6. Recommendations

Based on the findings and conclusions of this study, the following recommendations aim to improve maize and sorghum productivity through climate-smart agricultural practices (CSAP) in Northern Ghana. These recommendations are designed to be actionable and are directly linked to the study results.

The study highlighted that chemical fertilizers are widely used among smallholder farmers, but this reliance poses risks such as soil degradation and water contamination. To address this, we recommend a balanced fertilization approach that combines chemical and organic fertilizers. This strategy supports soil health and sustainable productivity.

This can be achieved through the organization of farmer training programs on the proper use of chemical fertilizers and the benefits of organic alternatives. Introduce soil testing services to guide fertilizer application based on specific nutrient needs. Agricultural extension services can play a key role in educating farmers on the integration of organic matter (e.g., compost, manure) with chemical fertilizers to ensure balanced nutrient management

## Ethics Approval and Consent to Participate:

This study received ethics approval from the University for Development Studies, Tamale, and all participants provided informed consent to participate.

## Consent for Publication

All individuals mentioned in this manuscript have provided their consent for publication.

## Availability of Data and Materials

The data and materials supporting the findings of this study are available upon reasonable request.

## Competing Interests:

The authors declare no competing interests.

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## Authors' Contributions:

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