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Climate risks and agroforestry adoption in food crop farms: evidence from rural Ghana

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Agroforestry is increasingly promoted as an important climate adaptation and mitigation strategy, yet its adoption can be hampered or facilitated by farmers' climate change experiences and perceived risks, as climate risks are associated with smallholder farmers' agricultural innovation adoption decisions. In Ghana, agroforestry is promoted largely in cocoa and cashew-based farming systems, with limited knowledge of its adoption in food crop farming systems, where land degradation and farm expansion are high. Grounded in the protection motivation theory and the innovation diffusion theory, this study assesses the influence of floods, droughts, rising temperature and erratic rainfall on smallholder farmers' willingness to adopt agroforestry in food crop farming systems in rural Ghana. Relying on a survey data from 535 smallholder farmers in four farming communities, we analyzed data using basic descriptive and logistic regression analyses. Results show that flood occurrence is the most crucial climate risk that influences farmers' agroforestry adoption decision. Similarly, having access to climate information services significantly shapes agroforestry adoption decision. Considering that floods are recurrent with associated impacts on crop production, agroforestry can serve as a transformative and resilient-building agricultural innovation for vulnerable smallholder farmers, if farmers have improved access to climate information services. Targeted policies and interventions that enhance farmers' knowledge of agroforestry and strengthen adaptive capacities through climate information services are highly recommended to guide informed adoption decisions in smallholder food crop farming systems.

KEYWORDS

climate change, climate vulnerability, climate extremes, sustainable agriculture, agri-food systems, smallholder agriculture

1 Introduction

Globally, climate change poses existential threats to agricultural activities. While Ghana and developing African economies alike contribute about 3% to global warming and climate change, changing climate may hinder the adoption of agricultural innovations, such as agroforestry, due to the adverse impact of climate change on Africa's agriculture (IPCC, 2022; Quandt et al., 2023). Agriculture is the backbone of many African economies, providing

employment to the majority of the labour force, and substantially contributes to gross domestic product and foreign income (African Development Bank, 2019; AGRA, 2023). However, the agricultural system in Africa is one of the most vulnerable to climate change. Being dominated by smallholder farmers who constitute the most resource-constrained population on the continent, the agriculture sector is adversely affected by rising temperature, flash floods, persistent droughts and pest invasion (AGRA, 2014; IPCC, 2022; Limantol et al., 2023). Similarly, low soil fertility and increasing land degradation exacerbate climate vulnerability on the continent (Critchley et al., 2023; Kuyah et al., 2021).

Smallholder farmers across many rural communities in Africa have reported severe climate impacts affecting their crops and livestock (Asare-Nuamah and Mandaza, 2020a; Chepkoech et al., 2018). Additionally, pest invasion due to climate change, for instance, fall armyworm invasion, results in about US\$9.4 billion loss annually (Eschen et al., 2021), posing severe threats to food security and poverty eradication efforts on the continent (Dotse et al., 2023; Hamadjoda Lefe et al., 2024). Studies project that due to climate change, African economies are likely to observe about 25–50% reduction in the production of cereals and grains (Sultan and Gaetani, 2016), crucial staple foods on the continent. This poses severe threats to a continent that has the majority of its population suffering from high food insecurity and malnutrition (FAO, 2025; FAO et al., 2026; WFP and FAO, 2015). Meeting the food security needs of the rising African population requires increasing its current food production capacity (Bruinsma, 2009; FAO, 2025).

Amidst being vulnerable to climate change, agricultural transformation can leapfrog African agricultural systems from the perilous impact of climate change, and enhance their socio-economic development (Chao et al., 2024; FAO, 2013; De Foresta, 2013). Similarly, to double food production in Africa, Bruinsma (2009) emphasizes that about 20% will come from land expansion and 80% from agronomic practices and improved crop varieties. This demonstrates the crucial role of agricultural innovations in Africa's agricultural transformation (Gurib-Fakim, 2015). Agroforestry is recognized as one of the promising agricultural innovations essential for boosting Africa's agricultural transformation. According to Balla (2024), ICRAF refers to agroforestry as integrating food crops, woody perennials and/or livestock on the same field, plot or farm. Crop/woody perennials/livestock integration offers substantial ecological and socioeconomic benefits (Raj et al., 2024).

Agroforestry offers several ecological benefits including: carbon and nitrogen sequestration by woody perennials and lands (Haskett et al., 2019), enhanced biodiversity and ecosystem services (Mosquera-Losada et al., 2020; Udawatta et al., 2019), improved evapotranspiration (Verchot et al., 2007), serving as wind breaks (Kachova et al., 2016; Yukhnovskiy et al., 2021), reduction of crop pests (Akesse-Ransford et al., 2021), desertification and erosion (Córdova et al., 2019), and water loss (Padovan et al., 2015). It is also associated with improved microclimate, soil structure and fertility (Rigueiro-Rodríguez et al., 2021). Furthermore, the ecological benefits derived from agroforestry contribute to the flowering of crops, resulting in improved yields. Thus, from a socioeconomic perspective, agroforestry contributes to improving yields with rippling effects on improved household food security, nutrition, health, wellbeing and income (Chemura et al., 2021; Kumar et al., 2015; Quandt et al., 2017, 2023), as well as improved access to forest products (Singh et al., 2021). Implicitly, agroforestry can be an important agricultural innovation to

tackle Africa's rising poverty (Diop and Asongu, 2021) and food insecurity (Hamadjoda Lefe et al., 2024). Nevertheless, studies have reported trade-offs associated with agroforestry, such as high labour demand and threats to native biodiversity, which partly contribute to its low adoption (Allakonon et al., 2022; Ghosh-Jerath et al., 2021; Ollinaho and Kroger, 2021).

The low adoption of agricultural innovations, including agroforestry, poses significant challenge to Africa's agriculture, especially in countries affected by land degradation and deforestation, such as Ghana (Akesse-Ransford et al., 2021; Amare and Darr, 2020, 2023; Kumar et al., 2015). According to Kosmowski et al. (2020) and Stevenson and Vlek (2018), the average rate of adoption of emerging agricultural innovations is about 4%. Specific to agroforestry adoption, Nkurikiye et al. (2024) indicate that farmers' limited involvement in agroforestry processes and decision-making, and their low knowledge of agroforestry management, account for its low adoption. Additionally, agroforestry options and extension services often do not align with farmers' local contexts and preferences, leading to low adoption. These barriers highlight how crucial formal and informal institutions, such as extension services, state policies, land tenure regimes and sociocultural norms, can shape decision-making and promote agroforestry adoption, especially those that participatorily engage farmers in co-creation and collective decision-making. Notwithstanding these barriers, there is a noticeable increase in agroforestry adoption among smallholder farmers in many parts of Africa (Balla, 2024; Lungu et al., 2024; Mbanze et al., 2022; Ngango et al., 2024; Quandt et al., 2017).

Policy-wise, improving agroforestry adoption requires understanding the contexts and realities of smallholder farmers to ensure that agroforestry options are suitable to their needs and preferences (FAO, 2013; Nkurikiye et al., 2024; Wijeratne and De Silva, 2024). Studies have explored farm-level and farmers' characteristics as well as institutional factors that enable or hinder the adoption of agroforestry (De Foresta, 2013; Kumah et al., 2024; Lungu et al., 2024; Nkurikiye et al., 2024; Nunoo and Owusu, 2017; Oliver et al., 2024). For instance, De Foresta (2013) notes that access to quality seeds, extension services and markets creates an enabling environment for agroforestry adoption. Essentially, institutional programs and interventions that prioritize improved access to seed varieties, markets, (non)digital extension and climate information services (CIS) can strengthen farmers' adoption decisions (Madaki et al., 2025). However, given the shortfalls with institutional programs including insufficient budget, uneven distribution of resources and bureaucratic decision-making processes, these can create unequal adaptive capacity among farmers, as only farmers who receive these services are more likely to adopt agroforestry (Ullah et al., 2022). Nevertheless, even for farmers who receive improved access to these services, conflicts and sociocultural norms related to land tenure, community and household decision-making can influence adoption among farmers in the same context. For instance, given the importance of secure land tenure in farm investment decision, farmers without secure land tenure can be disadvantaged in adopting agricultural innovations (Asare-Nuamah et al., 2024; Critchley et al., 2023), even if they have improved access to essential services.

Similarly, factors, such as tree shade and density, soil properties, and crop varieties' suitability to local climate, also play a vital role in agroforestry adoption (Isaac et al., 2007; Nunoo and Owusu, 2017). Asare-Nuamah et al. (2025a) show that farmer's preference for fruit and non-fruit trees in agroforestry systems are

highly dependent on ecological conditions - soils, climate and the ability of specific trees to thrive in specific conditions. Implicitly, farmers will adopt specific trees in agroforestry systems if they are conducive to their agroecological contexts and soil properties. This highlights the need for government and policymakers to adopt targeted interventions for specific agroecological zones, thereby boosting the potential for adoption among farmers. Additionally, farmers' socio-demographic characteristics, such as agroforestry knowledge, farm size, and educational levels, as well as access to credit, are crucial for agroforestry adoption (Kumah et al., 2024; Oliver et al., 2024). Thus, differences in farmers socio-demographic characteristics can result in differential adoption capacities.

While acknowledging agroforestry as an important climate change adaptation strategy, Quandt et al. (2023) indicate that the literature has focused on factors influencing agroforestry adoption, farmers' perspective of agroforestry benefits and the potential of agroforestry as a buffer for food security and adaptive capacity. The authors also identified three major gaps in the literature: (1) limited understanding of how different climate hazards influence agroforestry and the associated benefits of agroforestry during specific hazards; (2) uneven spatial distribution of agroforestry research; (3) lack of research that integrates socioeconomic and biophysical factors. While existing studies in Ghana contribute partially to address the second and third gaps, particularly from cocoa and cashew agroforestry perspective (see Amerino et al., 2024; Asare et al., 2014; Asitoakor et al., 2022; Hawkins et al., 2024; Kumah et al., 2024; Nunoo and Owusu, 2017; Oliver et al., 2024; Olwig et al., 2024; Yamoah et al., 2021), there are currently limited studies that explore how various climate variables influence agroforestry adoption, particularly outside cocoa and cashew agroforestry systems in Ghana. While Hashmiu et al. (2025) attempted to address climate-agroforestry nexus, they also focused on cocoa agroforestry.

Understanding the influence of climate change on agroforestry adoption, particularly in food crop farming systems, novelly contributes to the development and implementation of targeted policies and interventions for specific agroecological zones based on climate risks. The study also advances the literature on climate change and agroforestry adoption by specifically looking at climate risks that inform farmers' decision to adopt agroforestry in food crop farming systems, and the extension and delivery services needed to enhance farmers' capacity for informed decision. This study fills this gap by assessing how climate change, such as rising temperature, floods, and droughts, influence agroforestry adoption in smallholder food crop farms. Unlike the existing studies in Ghana, we depart from cocoa and cashew agroforestry, which has received significant policy and research attention, and focus on food crop farmers, given that they face severe climate change impact (Apuri et al., 2018; Asare-Nuamah and Botchway, 2019b; Baffour-Ata et al., 2021) and food insecurity (Kumeh, 2024) amidst limited attention. Also, rising deforestation and land degradation through agricultural extensification and expansion in smallholder food crop farming systems (Barenblitt et al., 2021; Environmental Protection Agency, 2002; Owusu et al., 2024) necessitate the need for agroforestry. This study, which contributes to strengthening climate resilience and agroforestry adoption among food crop farmers in Ghana, responds to the following research questions: (1) What are farmers' climate change experiences and perceived risks? (2) To what extent do farmers' climate experiences and perceived risks influence their willingness to adopt agroforestry in food

crop farms? (3) Do climate information services (CIS) influence farmers' agroforestry adoption?

2 Theoretical underpinning of the study

The present study drew on the protection motivation and the innovation diffusion theories as the theoretical anchor for understanding how climate risks influence farmers' willingness to adopt agroforestry. The protection motivation theory argues that shocks and stressors pose adverse impacts or threaten livelihoods and food security of individuals, likely encouraging them to protect themselves by implementing strategies that insulate them from the shocks or minimize the threats and impacts on their livelihoods (Rogers, 1975). The extent of climate vulnerability and impacts on smallholder agriculture and subsistence-based livelihoods have been highlighted in the literature, globally, especially in developing regions, such as Africa (Hamadjoda Lefe et al., 2024; Ullah et al., 2024). Thus, the threats posed by climate change serve as the motivation for farmers, government and development actors to implement adaptation and coping strategies, enabling smallholder farmers to mitigate climate impacts on their agricultural activities and livelihoods.

However, not all climate experiences and perceptions of vulnerable farmers may lead to climate action, as Mahmood et al. (2020) have reported unwillingness to implement climate adaptation measures among fatalistic farmers in Pakistan based on their religious orientation Cobbinah and Anane (2016) argue that such climate misconceptions can hinder the implementation of adaptation measures. Additionally, studies have shown the adoption of diverse climate adaptation and coping strategies among farmers in Ghana who associate climate change to spirituality or the anger of God (Asare-Nuamah et al., 2019), revealing contextual differences in how perception shapes climate adaptation. This concurs with Hiron et al. (2018) that psychological adaptation strategies are practiced among smallholder farmers to cope with climate change given their belief that climate-related problems can be mitigated through spiritualism or fatalism.

To mitigate climate change impacts, agroforestry has been promoted in diverse agricultural systems, including the cocoa and cashew sectors in Ghana, as a promising agricultural innovation. However, uptake remains low partly due to low diffusion, poor understanding of the technical effectiveness, environmental-friendliness, social acceptance and economic viability of the innovation (Asare-Nuamah et al., 2022; Critchley, 2007). The innovation diffusion theory offers a deeper understanding of the enablers and barriers to innovation adoption including agroforestry. According to Rogers (2003), the extent of innovation communication and diffusion substantially increases acceptance and adoption. Thus, the innovation diffusion theory recognizes the roles of innovation diffusion and communication agents, such as extension and advisory support service providers, in spreading information about a particular or a mix of innovations to smallholder farmers either through digital and non-digital communication channels. Essentially, CIS related to changing rainfall and dry season patterns, when to plant, specific improved crop and tree species capable of withstanding harsh climatic conditions among others, can allow farmers to make informed decisions, as they gain in-depth understanding of how to effectively implement

innovations (Asare-Nuamah et al., 2019). However, not all innovations are equally diffused among farmers, which creates uneven capacity for adoption. For instance, in resource-constrained environments, extension services are faced with limited budgetary provision, inadequate technical and materials support, and high extension-farmer ratio, which affect the diffusion of innovations (Asare-Nuamah et al., 2019; Ullah et al., 2022). Similarly, rural farmers receive limited extension support, which hinder their adoption of emerging innovations (Asare-Nuamah et al., 2019).

Apart from the role of extension agents in farmers' adoption decisions, the innovation diffusion theory also recognizes the influence of human capital, environmental and socioeconomic conditions on innovation adoption. As such, different conditions of human capital, environmental and socioeconomic characteristics result in differential capacity among farmers (Antwi-Agyei et al., 2023). Studies have shown that compared to the poor, resource-endowed farmers with higher educational qualifications, better social networks and improved ownership and access to land, inputs and other essential resources as well as those in urban communities have higher chances of adopting innovations (Antwi-Agyei et al., 2023; Ullah and Bavorova, 2025). Also, sociocultural norms and values that dictate who owns resources and make household decisions significantly discourage innovation adoption, especially among landless women, youth and marginalized groups in patriarchal societies (Ullah and Bavorova, 2025). Additionally, policies and programs that restrict access to and use of natural resources including land, and water, can adversely discourage implementation of climate adaptation strategies, as reported in the case of large-scale afforestation projects (Ullah et al., 2025). From the foregoing discussion, it is evident that the protection motivation

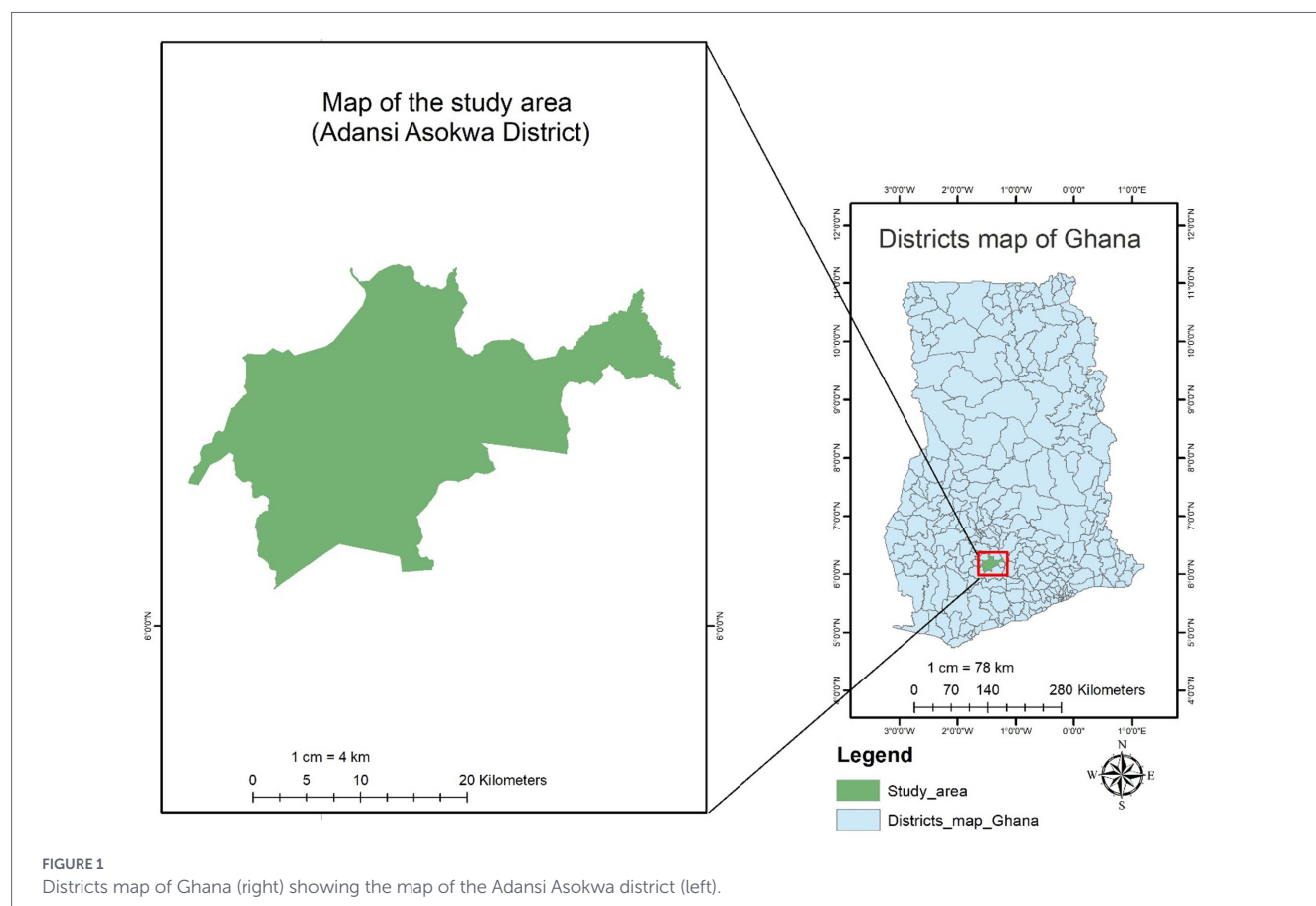
theory and the innovation diffusion theory, which have been applied in diverse fields, such disaster management and agricultural innovation adoption (Asare-Nuamah et al., 2022), are suitable for understanding the willingness to adopt agroforestry based on farmers' perceived climate risks.

3 Methodology

3.1 Study design and context

A cross-sectional survey was adopted to assess farmers' climate change experiences and perceived impacts and their influence on agroforestry in rural Ghana. The cross-sectional design allowed the inclusion of farmers with diverse characteristics (e.g., gender, educational level, locality, farming experience etc.) in the study to enable a broader insight into the adoption of agroforestry among these farmers. This is important considering that farmers are not homogenous and subtle differences in their socioeconomic conditions can influence their adoption decision. The study was conducted in the Adansi Asokwa district in the Ashanti region of Ghana (Figure 1) where farmers engage largely in food crop production as well as cash crops, such as cocoa (Asare-Nuamah et al., 2019; Asare-Nuamah and Botchway, 2019a).

The Adansi Asokwa District is located between longitudes 1.50°W and 1.5°W and latitudes 1.4°N and 6.30°N (MoFEP, 2021). The district shares border with the Adansi North District in the north, the Adansi South District in the south, the Bosome Freho District in the east and



the Obuasi East District in the west. The geographic size of the district is 713.30 km² and represents 2.94% of the Ashanti region total surface area. The Adansi Asokwa District is predominantly rural and was part of the Adansi North district until its establishment as a separate district in 2018 (GSS, 2014; MoFEP, 2021). The district is characterized by high temperatures and significant rainfall, typical of the semi-deciduous agroecological zone and the semi-equatorial climate. Average rainfall ranges from approximately 1,250 mm to 1,750 mm, with a mean annual temperature of 27 °C (GSS, 2014). The minimum and maximum mean monthly temperature in the district is 26 °C and 30 °C. The rainfall pattern in the district is bimodal, with the major rainfall season occurring from April to July and the minor season from September to November. The dry spell generally lasts from December to March, with February to March being the hottest months when the harmattan dry spell is severe. According to GSS (2014), these climatic conditions support agricultural activities, making smallholder agriculture the primary source of employment for 77% of the labor force. The district produces food crops like cassava, maize, yam, plantain, and cocoyam, along with cash crops, particularly oil palm, citrus, and cocoa (MoFEP, 2021).

However, agriculture in the district is highly vulnerable to climate change. Reports indicate that rising temperatures, erratic rainfall, windstorms, floods, and droughts, as well as threats from fall armyworms have led to drastic reductions in yields, compromising household food security (Asare-Nuamah, 2021; Asare-Nuamah and Botchway, 2019a). For instance, a 30-year rainfall and temperature analysis by Asare-Nuamah and Botchway (2019a) revealed increasing rainfall trends of 3.32 mm and 1.59 mm for the minor and major raining seasons, respectively. Similarly, the authors observed that temperatures were rising across seasons, with the magnitude of rising temperature being 0.02 °C for the minor rainfall season, 0.01 °C for the major rainfall season, and 0.03 °C for the dry season (see Appendix 1–3). Similar observations were also reported for wind speed. According to Asare-Nuamah and Botchway (2019a), farmers' climate perceptions and experiences, such as early sunshine, long duration of daily sunshine and the associated rising daily temperature, and unpredictable rainfall patterns and volumes (e.g., late onset and early cessation of the raining season), as well as floods and droughts corroborated the results from the climate data analysis. Also, illegal gold mining activities and land degradation from forest exploitation pose significant threats to agriculture in the district, highlighting the need for agroforestry initiatives.

3.2 Sampling procedure, instrument design and administration

A two-stage random sampling was adopted. We initially selected two small communities and two large communities following the results from the 2010 population and housing census (GSS, 2014). We emphasize that while the 2021 population census offers more recent data on districts' population in Ghana, the data for the district is publicly not available at the time of the study, as the district report had not been released. Hence, we relied on the 2014 report for the district. The selection of two small and large farming communities was based on the understanding that a community's size or status (such as a rural or urban community) influences its level of development, access to resources and capacity to respond to climate shocks and stressors (Antwi-Agyei et al., 2014; Asare-Nuamah et al., 2025a).

Larger communities tend to share more urban characteristics, whereas smaller communities are typically rural in nature. This concurs with Wang et al. (2026) that urban communities tend to be more resilient than rural communities. Using the sample size selection technique by Krejcie and Morgan (1970) and proportional representation based on the number of households in each community as reported in the 2010 population census, the study further randomly selected 536 smallholder farmers from four communities. The number of households in the selected communities were 1,384, 835, 527, and 251, for Fumso, Anhwiaso, Akwansrem and Ayokoa, respectively. For the two large communities, 142 farmers, representing 26.5% of the sampled farmers were selected from Anhwiaso while another 236 (44.1%) farmers were selected from Fumso. Similarly, for the two small communities, 107 farmers representing 20% of the sample were selected from Akwansrem while 50 (9.4%) farmers were also selected from Ayokoa.

The survey questionnaire was developed based on the study objectives and existing literature (Amerino et al., 2024; Nkurikiye et al., 2024). It included multiple-choice, multiple-response, and open-ended questions aimed at gathering information on farmers' climate change experiences and perceived risks, willingness to adopt agroforestry, climate information sources and their socio-demographic characteristics. While actual adoption would have been preferred, the study rather used willingness to adopt considering that agroforestry is predominant in cocoa and not food crop farms (Asare-Nuamah et al., 2025a). As such, exploring farmer's willingness to adopt agroforestry in food crop farms based on their climate experiences and risks is imperative (Larbi-Koranteng et al., 2025). To enhance the face and content validity of the questionnaire, it was pretested with 10 farmers and reviewed by two experts (Creswell, 2014). This helped to avoid ambiguity and improved the wording of the questions, enhancing comprehension among the respondents. The questionnaire was designed using Kobo Toolbox, a reliable and robust online platform for surveys. Data collection took place from May to June 2024. Before the data collection began, three research assistants with data collection experience in the district were recruited and trained to ensure consistent and valid data collection. The questionnaire was administered face-to-face utilizing Kobo Toolbox's improved data management, which minimized duplication of data.

Upon obtaining institutional approval, the study adhered to ethical research principles by obtaining informed consent from participants. The objectives and purpose of the study were clearly explained to participants, helping them to make an informed decision about their participation. Only those who consented to take part in the study were included, ensuring that participation was voluntary. Additionally, the study guaranteed participants' rights to withdraw at any time and ensured the confidential and anonymous use of their information.

3.3 Data analysis

The data was initially screened and cleaned in Kobo Toolbox, leading to the removal of 1 empty response. The Kobo Toolbox Excel file was transferred to SPSS version 21 for preliminary analysis and further cleaning. In all, 535 responses were used for the analysis. Basic descriptive statistics were computed in addition to bar charts. Cronbach alpha was computed to explore the reliability of the instrument, yielding 0.841 coefficient, which exceeded the

0.70 threshold (Pallant, 2016). A chi square test of independence was also computed to assess the association between respondents' demographic characteristics and their communities. Two binary logistic regression models were computed to assess farmers' agroforestry adoption decisions. Binary regression was chosen as the dependent variable has binary outcomes. The dependent variable in both models was whether farmers are willing to adopt agroforestry. The first model focused on the influence of climate change experiences, perceived risks and willingness to adopt agroforestry while the second model dealt with CIS and agroforestry adoption. Following Long and Freese (2014), we define y^* as a latent variable ranging from $-\infty$ to $+\infty$ with the structural model is given in Equation 1 as:

$$y_i^* = x_i^T \beta + \varepsilon_i \quad (1)$$

Where y_i^* is the exact but unobserved dependent variable for observation i ; x is the vector of independent variables; ε_i is the error term, and β is the vector of regression coefficients which we target on estimating. The observed binary dependent variable has two values, typical coded as 0 for a negative outcome (in this case when the individual is not willing to adopt agroforestry) and 1 for a positive outcome (in this case when the individual is willing to adopt agroforestry). The measure equation defines the link between the binary observed variable y and the continuous unobserved variable y^* as:

$$y_i = \begin{cases} 1 & \text{if } y_i^* > 0 \\ 0 & \text{if } y_i^* \leq 0 \end{cases} \quad (2)$$

Two distributions of the error term (ε) are commonly used for estimating the model, both with an assumed mean of 0, but the variance differs between the two models. The probit model assumes a standard normal distribution with a variance equal to 1, while the logit model assumes a specific value for the variance equal to $\frac{\pi^2}{3}$ (Long and Freese, 2014). Despite this difference, the

two models are very similar. In fact, the coefficients estimated in the logit model are roughly 1.7 times larger than those in the probit model (Long and Freese, 2014). For this analysis, the logit model was chosen because its coefficients are easily interpretable in terms of odds ratios.

The independent variables in the first model included climate variables, such as flood occurrence, drought occurrence, drought intensity, temperature, and rainfall occurrence and intensity as well as rainfall onset, rainfall cessation, and impacts on yields, income, food security and agricultural expenditure. These variables were measured as 1 indicating farmers' affirmation of a particular climate incidence, otherwise 0. In the case of flood, high correlation between flood occurrence and intensity resulted in excluding flood intensity in the model. In addition to the climate variables, farmers' demographic information including gender, level of education, age, years of farming experience, access to credit, land size, access to extension, and farmer-based organization membership were included in the model. Gender was categorized as 0 for men and 1 for women. Land size, years of farming experience and age were also continuous variables and measured in acreage, total

number of years engaged in agriculture and age, respectively. The educational level of respondents was collected in a categorical (ordinal) manner comprising 0 for no formal education, 1 for basic education, 2 for secondary education, and 3 for tertiary education. Access to credit, access to extension services, and farmer-based organization (FBO) membership were all binary variables, with 0 for no and 1 for yes. In the second model, the independent variables included access to CIS and all the demographic variables from the first model.

4 Results

4.1 Farmers' demographic profile

The respondents' distributions based on their socio-demographic characteristics are presented in Table 1. About 55% of the respondents were males while 45% were females. In terms of education, 87% of the study respondents were educated. Among this population, 50.11, 35.55 and 14.34% had basic, secondary and tertiary educational qualifications, respectively. More than half of the respondents (73.3%) did not have access to credit as opposed to 26.7% who had access to credit. For extension services, 53.5% had access to extension as opposed to 46.5% who had no access to extension services. Similarly, about 75.33% of the respondents indicated they received CIS. The mean years of farming experience among the respondents was 17 years while the average farm size was 6 acres, which is equivalent to about 2 hectares. Specific to agroforestry adoption, 80.93% affirmed their willingness to adopt agroforestry while 19.07% were unwilling to adopt agroforestry. The mean age of the respondents was 42 years, with 23 years being the minimum age and 78 years as the maximum age. Also, while 55.51% of the respondents belonged to FBOs, 44.49% of the respondents were not. The chi square results showed a significant difference in access to credit, extension, CIS and membership in FBOs based on participants' communities, which highlights to a greater extent, differential capacities of respondents.

4.2 Climate change experiences and perceived risks

Over 95% of the study participants have observed changes in the climate within their communities. Specifically, while 65.54% have observed a decrease in the occurrence of flood, 34.46% reported an increase in flood occurrence. Furthermore, 77.72% of the respondents indicated an increase in flood intensity, compared to 22.28% who reported a decreasing flood intensity. The majority of respondents (98.50%) reported an increase in the occurrence of droughts, and 98.32% noted an increase in drought intensity. Finally, 99.25% of participants stated that they have observed a rising temperature trend. Rainfall occurrence was reported to be increasing among 75.89% of the respondents, as opposed to 24.11% who reported otherwise. Specific to rainfall onset, 58.88 and 41.12% reported early and late onset of rainfall, respectively. The result on rainfall cessation was indifferent as 50.09 and 49.91%, respectively, indicated late and early cessation of rainfall. The observed changes were reported to exert severe impacts on respondents' agricultural activities and livelihoods. About 99.25% of them reported a reduction in yields and income. Similarly, 94.58% indicated that the observed changes increase agricultural

TABLE 1 Respondents' socio-demographic characteristics.

Variable	Frequency	Percentage	Chi square (<i>p</i>)
Gender			
Male	293	54.77	0.821
Female	242	45.23	
Highest level of education			
No formal education	68	12.71	0.833
Formal education (basic, secondary, and tertiary education)	467	87.29	
Access to credit			
Yes	143	26.73	0.042*
No	392	73.27	
Access to extension services			
Yes	286	53.46	0.001*
No	249	46.54	
Access to climate information services			
Yes	403	75.33	0.000*
No	132	24.67	
FBO membership			
Yes	297	55.51	0.001*
No	238	44.49	
Willingness to adopt agroforestry			
Yes	433	80.93	0.139
No	102	19.07	

Variable	Mean	Standard deviation	Chi square (<i>p</i>)
Years of farming experience	17	1.05	0.295
Land size (acreage)	6.04	5.02	0.28
Age	42.28	12.44	0.209

**p* < 0.05.

expenditure and hardship (poverty). Reduction in food security was reported among 96.82% of the respondents.

4.3 Climate risks and agroforestry adoption

The regression estimation results on the influence of climate variables and socio-demographic characteristics on farmers' willingness to adopt agroforestry are presented in Table 2. The results show a significant positive association between flood occurrence and farmers' willingness to adopt agroforestry. This implies that farmers who experience floods are more likely to make informed decision to adopt agroforestry. The odds ratio shows that a unit increase in farmers' experience of floods increases the odds of willingness to adopt agroforestry by 4.5%. Apart from drought intensity with a negative association, other climate variables, such as rainfall cessation, drought occurrence, temperature, rainfall intensity and occurrence, and rainfall onset, had a positive association with adoption, although all these were statistically non-significant.

Specific to climate risk, the results reveal a non-significant negative relationship between climate change impact on yields, expenditure, and food security, and farmers' willingness to adopt agroforestry.

Again, the association between climate impact on income and decision to adopt agroforestry is non-significant. In terms of farmers' demographic profile, there is a significant positive relationship between years of farming experience and willingness to adopt agroforestry (*p* = 0.062). From the odds ratio, as the years of farming experience increase by 1, farmers' willingness to adopt agroforestry also increases by 3.7%. Thus, more experienced farmers are likely to make informed decisions to adopt agroforestry. Also, there is a significant negative association between age and willingness to adopt agroforestry, as an increase in age reduces willingness to adopt by 3.6%. Implicitly, younger farmers, especially the youth, are more likely to make informed decision to adopt agroforestry.

4.4 Climate information services and agroforestry adoption

From Figure 2a, the respondents receive diverse CIS. The most common CIS received by farmers relate to information on rainfall patterns (99.5%), followed by information on when to plant (98.5%), farm management (97%), and agrochemicals applications (96.8%). The others include information on pests

TABLE 2 Relationship between climate change and agroforestry adoption.

Variables	Coefficient	Odds ratio	Robust std. err.	z	P > z	[95% conf. interval]	
Climate variables							
Flood occurrence	0.0438853	1.044862	0.0122378	3.59	0.000	0.0198995	0.067871
Drought occurrence	0.7989922	2.223299	1.236019	0.65	0.518	−1.623561	3.221545
Drought intensity	−0.5560218	0.573486	0.8186491	−0.68	0.497	−2.160545	1.048501
Temperature	0.3822172	1.46553	1.289576	0.30	0.767	−2.145306	2.909741
Rainfall occurrence	0.32601	1.385429	0.3446549	0.95	0.344	−0.3495013	1.001521
Rainfall intensity	0.7802327	2.18198	0.5235442	1.49	0.136	−0.245895	1.80636
Rainfall onset	0.2831787	1.327342	0.3111477	0.91	0.363	−0.3266596	0.8930169
Rainfall cessation	−0.2053896	0.81433	0.2922598	−0.70	0.482	−0.7782083	0.3674291
Climate impact variables							
Impact on yields	−0.582011	0.5587735	1.199478	−0.49	0.628	−2.932944	1.768922
Impact on income	0.1091804	1.115364	1.159447	0.09	0.925	−2.163294	2.381655
Impact on expenditure	−0.7098254	0.4917301	0.5134882	−1.38	0.167	−1.716244	0.296593
Impact on food security	−0.2953409	0.7442778	0.6482612	−0.46	0.649	−1.56591	0.9752276
Demographic variables							
Gender	−0.1671718	0.8460543	0.2647709	−0.63	0.528	−0.6861132	0.3517696
Age	−0.0368165	0.963853	0.0153719	−2.40	0.017	−0.0669448	−0.0066882
Years of farming experience	0.0366749	1.037356	0.0205878	1.78	0.075	−0.0036764	0.0770262
Land size	0.0663416	1.068592	0.0458143	1.45	0.148	−0.0234528	0.156136
Education							
Basic education	0.235283	1.265267	0.3952828	0.60	0.552	−0.5394571	1.010023
Secondary education	0.3089645	1.362014	0.4593684	0.67	0.501	−0.5913811	1.20931
Tertiary education	0.0300589	1.030515	0.515729	0.06	0.954	−0.9807514	1.040869
Access to credit	0.3088035	1.361795	0.2947904	1.05	0.295	−0.268975	0.886582
FBO membership	0.0352373	1.035866	0.4946061	0.07	0.943	−0.9341728	1.004648
Access to extension	0.5762764	1.7794	0.4946515	1.17	0.244	−0.3932228	1.545776
_cons	0.0003663	1.000366	2.044696	0.00	1.000	−4.007164	4.007897

Dependent variable: willingness to adopt agroforestry.

and disease control (89.8%) and what type of crop to plant (88.1%). The sources of farmers' CIS are reported in Figure 2b. The majority of the farmers receive CIS through radio and from their peers (91.8% each). About 66 and 54.3% of the farmers receive CIS from community information centers and extension service providers, respectively. The internet (37.2%), television (40.9%), and FBOs (43.7%) were the least sources of CIS among the farmers.

The results of the regression analysis of the influence of CIS on willingness to adopt agroforestry are presented in Table 3. It is evident from Table 3 that there is a strong positive association between receiving CIS and willingness to adopt agroforestry. Per the odds ratio, willingness to adopt agroforestry increases by 80% with a unit increase in receiving CIS. Indicatively, farmers who receive CIS are more willing to adopt agroforestry than those who do not receive CIS. As observed in the first model (Table 2), Table 3 also shows that years of farming experience and age are significant predictors of willingness to adopt agroforestry. There is also a non-significant association between land size, education, access to credit, access to extension, FBO membership, gender and farmers' willingness to adopt agroforestry.

5 Discussion

The results from the study are discussed under the following thematic areas, which relate to the objectives of the study.

5.1 Climate experiences and perceptions among farmers

Like many parts of Africa, smallholder farmers in the study area reported climate change experiences, which negatively affect their agricultural activities. Floods, droughts, rising temperatures and unpredictable and erratic rainfall patterns are common phenomena among smallholder farmers in the study communities. Previous studies in the study area similarly reported that smallholder farmers are highly vulnerable to floods, droughts, rising temperatures and erratic rainfall patterns (Asare-Nuamah and Amungwa, 2021; Asare-Nuamah and Botchway, 2019a).

Across Ghana's agroecological zones, studies have revealed pervasive changes in climate due to rising temperatures and unpredictable rainfall patterns (Asare-Nuamah and Botchway, 2019b). The results

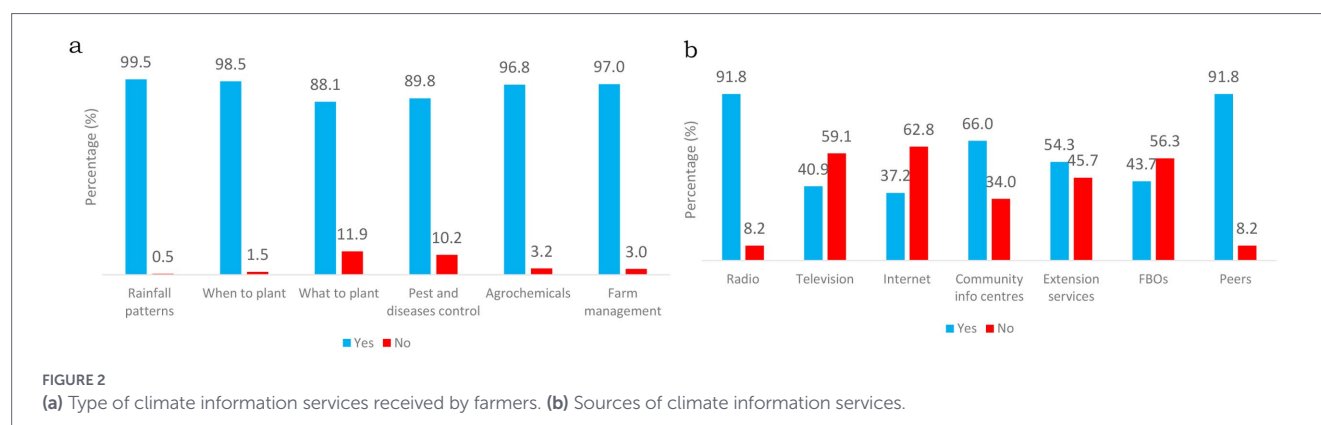


TABLE 3 Relationship between receiving climate information services and willingness to adopt agroforestry.

Variables	Coefficient	Odds ratio	Robust std. err.	z	P > z	[95% conf.interval]	
CIS	0.5880598	1.800492	0.25904	2.27	0.023	0.0803507	1.095769
Gender	−0.1004462	0.9044338	0.2605779	−0.39	0.700	−0.6111695	0.4102772
Age	−0.0364913	0.9641665	0.0147945	−2.47	0.014	−0.0654879	−0.0074947
Yeas of farm experience	0.0390534	1.039826	0.0207557	1.88	0.060	−0.001627	0.0797337
Land size	0.0562626	1.057875	0.0426818	1.32	0.187	−0.0273922	0.1399175
Education							
Basic education	0.2176105	1.243103	0.4157931	0.52	0.601	−0.5973289	1.03255
Secondary education	0.321504	1.379201	0.4824178	0.67	0.505	−0.6240176	1.267026
Tertiary education	−0.0507031	0.9505609	0.544965	−0.09	0.926	−1.118815	1.017409
Access to credit	0.2942837	1.342165	0.2879	1.02	0.307	−0.2699899	0.8585573
FBO membership	0.1118266	1.118319	0.4434907	0.25	0.801	−0.7573992	0.9810525
Access to extension	0.4217546	1.524634	0.4657213	0.91	0.365	−0.4910422	1.334552
_cons	1.475849	4.37475	0.8818328	1.67	0.094	−0.2525111	3.20421

Dependent variable: willingness to adopt agroforestry.

from the present study are consistent with reports from several parts of Africa. For instance, in Zimbabwe and across the Southern Africa region, decrease in average rainfall, increased frequency of droughts and recurring floods show evidence of climate variability and change (Bola et al., 2014). Chepkoech et al. (2018) also revealed that in East Africa, particularly in Kenya, the shortness and unpredictability of the raining season coupled with high temperatures have intensified drought conditions, with significant implications on farm productivity.

The observed changes in climate across the African continent severely affect smallholder agriculture, resulting in drastic reduction in yields and agricultural income, increased pest invasion, and rising household food insecurity and agricultural expenditure (Asare-Nuamah, 2021). Particularly, Hamadjoda Lefe et al. (2024) showed that food insecurity across several countries is driven partly by climate vulnerability and changes. For instance, while vegetable production contributes substantially to farming households' food security, erratic rainfall patterns and rising temperature have drastically reduced vegetable yields, affecting households access and nutrition (Chepkoech et al., 2018). Future projections show that climate change is likely to cause a substantial reduction (about 25–50%) in major agricultural products, particularly grains and

cereals (Sultan and Gaetani, 2016), which are essential staple food for many poor and vulnerable households on the continent.

Undoubtedly, climate change can worsen poverty and hardship in already fragile and vulnerable smallholder agricultural communities, given their reliance on subsistence and rain-fed agriculture as the main source of livelihoods, coupled with the impacts of the COVID-19 pandemic and other socioeconomic barriers (Ablo et al., 2025; Cobbinah et al., 2025; Diop and Asongu, 2021). Consistent with the protection motivation theory, climate change poses severe threats to food security, poverty eradication and the livelihoods of smallholder agricultural households, necessitating the need to protect themselves through climate adaptation measures, such as agroforestry.

5.2 Agroforestry adoption as a response to climate change

Agroforestry can serve as an important adaptation strategy to offset and mitigate adverse climate change impacts in smallholder agricultural systems (Quandt et al., 2023). Yet farmers' willingness to adopt agroforestry is influenced by myriad factors, including climate extremes. The results from the study show that flood is the most important climate variable that influences farmers' willingness to

adopt agroforestry. This is consistent with the case of Rwanda and several other contexts where farmers' adoption of agroforestry is influenced by prevailing climatic conditions (Nkurikiye et al., 2024). Farmers in flood prone areas are likely to adopt agroforestry to mitigate the impacts of floods. Flood, occurrence or intensity, seriously affect agriculture, especially through soil erosion, choking of crops and disturbing the ideal soil pH for crops. This leads to crop failure or low productivity of crops. Rampant soil erosion and the presence of gullies in the study communities demonstrate the severity of floods in the study area. Thus, frequent and intense floods affect soil fertility, structure and texture. Hence, continuous flood affects overall productivity and yields, making agroforestry an essential innovation to address run-offs and water loss, as observed in Ecuador (Córdova et al., 2019) and Nicaragua (Padovan et al., 2015).

Integrating trees, particularly agrosilviculture, in flood- and drought-prone farming systems can strengthen soil aeration and porosity, leading to enhanced drainage capacity of soils and reducing erosion (Asare-Nuamah et al., 2025a). Studies from several parts of the world have reported that trees contribute to improving biodiversity, ecosystem services, and evapotranspiration (Mosquera-Losada et al., 2020; Udawatta et al., 2019; Verchot et al., 2007), which are essential for addressing floods and other climate-related challenges. Nevertheless, integrating trees in farms, especially in drought-prone areas, requires complementary irrigation systems, thereby providing water for the growth and productivity of trees (Haddad et al., 2026; Shiran et al., 2026). Consequently, policies and interventions that promote the supply and adoption of drought tolerant tree varieties, are highly essential in drought-prone areas, as observed in Ethiopia (Mekonnen, 2026) and China (Zhao et al., 2026).

5.3 Climate information services and agroforestry adoption

Climate information services are essential for climate change adaptation, as they provide invaluable information needed for informed decision-making among smallholder farmers (Antwi-Agyei et al., 2021). Information on what and how to plant, pest control and farm management are essential for tackling climate change. For agroforestry adoption, such information can aid farmers in selecting tree species and crop varieties suitable to their local climate and ecology, thereby enhancing effective agroforestry management. As noted by Nkurikiye et al. (2024), poor agroforestry knowledge affects both its adoption and effective management.

The results from this study show that majority of the respondents received CIS, such as what and when to plant, rainfall patterns, pests, and farm management, as well as agrochemical application, from diverse sources, including radio, peer-to-peer extension, extension and advisory service providers and community information centers. These CIS strategically position farmers to make informed decisions related to their agricultural activities. Our results show that access to CIS positively influences agroforestry adoption, which is consistent with the innovation diffusion theory (Rogers, 2003). Thus, farmers who receive CIS are more willing to adopt agroforestry than their counterparts.

Across the developing world, CIS and extension delivery are constrained by limited financial support, inadequate staffing, high extension-farmer ratio, logistical constraints among others (Madaki et al., 2025; Ullah et al., 2022). For instance, in Nigeria (Madaki et al., 2025) and Pakistan (Ullah et al., 2022) these constraints have been adversely resulted in uneven delivery of extension services, affecting the diffusion and

adoption of agroforestry. While digital-based climate information and extension services can reduce the systemic challenges associated with traditional extension, low literacy in smallholder African farming households and communities, rising food insecurity and poverty also impede digital extension delivery (Nkurikiye et al., 2024).

A recent study by Pienaaah et al. (2026) revealed that market-oriented and cost-sharing extension services are negatively impeded by rising food insecurity while access to remittances, joint household decision-making and female-headed households largely improve willingness to pay for fee-based extension services. It is, therefore, crucial for governments and development partners to intensify agroforestry knowledge through improved access to CIS among smallholder farmers. This can be achieved by strengthening the medium for disseminating CIS, such as radio, extension services, peer-to-peer extension, community information centers, and FBOs, given their strategic role in enhancing informed decisions among smallholder farmers (Antwi-Agyei and Stringer, 2021; Asare-Nuamah et al., 2019).

5.4 Influence of farmers' socio-demography on agroforestry adoption

Regarding demographic characteristics, the results show that years of farming experience and age are significant predictor of farmers' willingness to adopt agroforestry, which is consistent with a previous study in Rwanda (Nkurikiye et al., 2024). Implicitly, farmers with more years of farming experience are more likely to make informed agroforestry adoption decision compared to their counterparts. The role of years of farming experience in climate change adaptation is highly relevant, as farmers rely on their rich agroecological knowledge in making decisions to respond to climate change. Implementing agroecology requires an in-depth knowledge of the local context and experienced farmers are likely to rely on their rich and in-depth traditional agroecological knowledge to make an informed decision (Nkurikiye et al., 2024). Such knowledge production system is crucial for governing climate and environmental challenges within a particular context (Moe and Müller, 2024). However, years of farming experience alone might be insufficient to allow farmers to make informed decisions, as enabling sociocultural, economic and institutional conditions are equally relevant for farm investment decisions (Madaki et al., 2025; Ullah et al., 2022; Ullah and Bavorova, 2025). These can complement vulnerable but experienced farmers in making informed decisions to adopt agroforestry and other climate smart agricultural practices (Antwi-Agyei et al., 2023).

Additionally, the association between age and willingness to adopt agroforestry shows that younger farmers are likely to adopt agroforestry. This is partly because agroforestry is considered an innovative and sustainable farming practice, which is more appealing to the youth. Essentially, while agroforestry is traditionally an old farming practice in Africa, its association with climate and environmental change might make it more appealing to the youth. This is consistent with the argument that younger farmers have more interest in environmental and sustainability issues, making agroforestry acceptable among young farmers (Asare-Nuamah et al., 2025b). For instance, a global study of young climate and environment advocates at Conference of Parties (COP) of the United Nations Framework Convention on Climate Change showed that their interest relates largely to the promotion of sustainable practices and policies by state and non-state actors (Asare-Nuamah and Mandaza, 2020b). Similarly, as observed in the Republic of Congo, weak knowledge of agroforestry systems can result in different adoption rate among farmers, with more exposed and educated youths likely to adopt agroforestry.

5.5 Limitations of the study

Notwithstanding the interesting insights from the study findings, there are limitations associated with the study. Climate assessment was based on farmers' perceptions and experience and not on actual climate data. Also, as highlighted in the methodology section, the study focused on willingness to adopt agroforestry, which does not reveal actual adoption of agroforestry among farmers. Exploring actual agroforestry adoption rate among farmers and comparing to non-adopters would have offered a nuance understanding of the drivers of agroforestry adoption among farmers. Also, the study participants were selected from the households' population of the study communities using the 2010 population census data, limiting the sample size used. As such, the sample size used in this study is not a representative of all farmer population in the district, let alone the Ashanti region or Ghana as a whole. Additionally adopting quantitative approach to study a complex phenomenon like climate change may not offer richer insights into the lived experiences of farmers, making it essential for further studies to combine quantitative and qualitative approaches in understanding farmers' lived climate experiences.

6 Conclusion

The results from our study provide relevant insights into the influence of climate change on agroforestry adoption. We observe that farmers have experienced floods, droughts, rising temperatures, and erratic rainfall patterns. These changes severely affect agriculture yields, income, and household food security, and increase agricultural expenditure, thereby increasing hardship among vulnerable smallholder farmers. As such, agroforestry can serve as an important strategy to address climate risks. However, farmer's willingness to adopt agroforestry is influenced by their climate experiences and perceived risks, particularly flood. High prevalence of flood in the study area and its impacts on soil fertility and yields make agroforestry ideal for farmers in the study area. Integrating trees in food crop farms can help protect farmers from the adverse effects of floods as noted by the protection motivation theory. Implicitly, agroforestry can serve as a response to flood among farmers in flood prone areas. We equally observe the significant role of CIS in farmers' willingness to adopt agroforestry. Similarly, agroforestry adoption is influenced by years of farming experience and age. These results are consistent with the position of the innovation diffusion theory.

On the basis of the results, we recommend government and development partners to integrate agroforestry as a transformative adaptation strategy to address climate change, particularly in flood prone areas. Farmers in flood prone areas are likely to adopt agroforestry if they have a better knowledge of the importance of trees in tackling floods. It is therefore, crucial to strengthen CIS through relevant sources, such as extension, radio, community information centers and farmer-based organizations, to enable farmers to understand agroforestry. Climate information services should prioritize context-specific realities, such as what type of trees/perennials to integrate into farmers' agricultural activities based on soil and ecological characteristics, and how to manage agroforestry. This can increase farmers' willingness to adopt agroforestry in food crop farms. Additionally, targeted interventions that address inequality within and among men and women farmers in rural and urban communities can contribute to informed decision-making about innovation adoption. Further studies should

explore a broader assessment of the influence of climate risks on actual agroforestry adoption across different agroecological zones in Ghana and other similar contexts in Africa to enable the implementation of specific agroforestry solutions to different agroecological contexts. Such studies should prioritize and include adopters and non-adopters of agroforestry in rural and urban farming contexts.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, upon a reasonable request.

Ethics statement

The studies involving humans were approved by Center for Development Research Ethics Review Committee. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin because Oral informed consent was sought from study participants.

Author contributions

PA-N: Formal analysis, Data curation, Investigation, Methodology, Conceptualization, Writing – original draft, Writing – review & editing, Funding acquisition. EB: Writing – review & editing, Methodology, Writing – original draft, Formal analysis. AA-A: Writing – review & editing, Methodology. NN: Methodology, Writing – review & editing. MA-A: Conceptualization, Writing – review & editing.

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Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fsufs.2026.1882517/full#supplementary-material>

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