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Land Tenure Systems' Security and Adaptation Strategies Nexus to the Changing Climate in Northern Ghana

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Abstract: The nexus between land tenure systems security and smallholder farmers' investments in adaptation strategies in the changing climate is not well understood. This is a call to investigate the relationship between land tenure systems, security and climate adaptation strategies in northern Ghana. The land tenure system security employed for this study includes perceived tenure security, land use duration, land transfer, use, and exclusion rights. The study uses a three-stage sampling procedure to select 2934 farm households in northern Ghana. Using multivariate probit and Poisson models, the results reveal that smallholder farmers' perceived land tenure security is positively and significantly correlated with five (5) climate adaptation strategies. Land use/ownership duration, land use right, transfer right, and land exclusion right have a heterogeneous significant relationship with individual adaptation strategies. Notwithstanding, the land tenure systems' security has a significant positive relationship with climate adaptation intensity, except for land use duration and transfer rights. Policymakers should design context-specific land tenure reform policies that reflect local socio-economic realities to enhance farmers' land rights for effective investment in sustainable agriculture.

JEL: *Q13, Q15, Q54, R14*

***Keywords*:** *Climate adaptation, Ghana, Land tenure systems, Multivariate probit model, sustainable land management*

1. INTRODUCTION

In the global sought, there is growing concern about enhancing agricultural productivity to combat food security in the changing climate (Kabato *et al*., 2025). The impact of climate change on sustainable food systems is well documented (Fitchett *et al*., 2016). Climate change has induced an adverse effect on all economic sectors, particularly rainfed agriculture (Gemeda *et al*., 2023). That is, the changing climate reduces agricultural productivity and incomes, thereby increasing food insecurity and poverty in the global south (Aggarwal *et al*., 2019; Marie *et al*., 2020). The impact of the climate on smallholder farmers is enormous despite their critical role in food systems (Maiwashe Tagwi & Khoza, 2024). Incentivising smallholder farmers to enhance their adoption of climate mitigation strategies (Nchanji *et al*., 2023) has become a tropical concern to enhance farm productivity and other livelihood outcomes.

Climate adaptation strategies to mitigate the impact of climate change on agri-food systems have emerged in recent times. Several empirical studies demonstrated that climate adaptation strategies mitigate the impact of climate change on farm productivity while making the farmer more resilient (Diallo *et al*., 2020; Douxchamps *et al*., 2016; Gebre *et al*., 2023; Kone *et al*., 2024). For instance, Douxchamps *et al*. (2016) study revealed that

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farmers who adopted climate strategies are more food secure and less vulnerable to climate change in West Africa. But the authors acknowledge that the adaptation strategies' impact on food security and vulnerability varies across regions and districts/ communities due to different climate adaptation typologies. Farmers in Mali who adopted organic fertilizer and improved maize seeds have higher farm yields and are more food secure than their counterparts (Diallo *et al*., 2020). In Pakistan, climate adaptation strategies reduce household food insecurity and poverty among rural farm households (Ali & Erenstein, 2017). In Ghana, studies revealed a positive impact of climate adaptation measures on farm productivity and food insecurity among smallholder farmers (Adams *et al*., 2025; Asare-Nuamah & Mandaza, 2021; Oduro *et al*., 2024; Tambo, 2016). Despite the significant contribution of climate adaptation strategies to farm productivity and food security, climate adaptation strategies among smallholder farmers still remain low in Africa, especially in West Africa (Carr *et al*., 2022; Okoronkwo *et al*., 2024). Several reasons account for the low climate adaptation strategies, which include poor access to production credit, extension services, climate information, and land tenure insecurity (Alawode, 2025; Funke & Munyaradzi, 2025; Manja *et al*., 2025; Touch *et al*., 2024).

Secure land tenure has emerged as a critical factor in determining smallholder farmers' decision to adopt climate adaptation strategies (Chavula & Turyasingura, 2022; Murken & Gornott, 2022; Thinda *et al*., 2020). Access to land is a fundamental human right, and when smallholder farmers have secure land rights, they are more incentivized to adopt sustainable climate mitigation measures against climate change (Qian *et al*., 2022). Secure land tenure has been demonstrated to contribute to the adoption of sustainable farming practices and food systems (Alban Singirankabo & Willem Ertsen, 2020; Holden & Ghebru, 2016; Olagunju *et al*., 2023; Yang *et al*., 2022; Zheng *et al*., 2023). But these studies have mixed findings, as others found a positive effect of secure land rights on adoption climate strategies (Robinson *et al*., 2014; Vu & Goto, 2020), others found negative (Zahonogo & Séogo, 2019) and/ or no significant effect at all (Yang *et al*., 2022).

Most of these studies employed a single indicator to measure land tenure security. This may not reflect the reality of the land tenure security effect on individual climate adaptation strategies (Kossigan & Edgeweblime, 2023). Different secure land tenure rights under customary land tenure in West Africa might have a different directional influence on climate adaptation strategies. Recognizing these, this study expands the debate by using a multi-dimensional secure land tenure right, such as land tenure security, land transfer rights, land use rights, land exclusion rights, and land ownership duration, to investigate their associations with climate adaptation strategies in northern Ghana. The novelty of this study is that these secure land tenure systems have different directional associations with climate adaptation strategies. Thus, land tenure systems' security has heterogeneous implications for the sustainability of climate adaptation strategies.

The rest of the paper is organised as follows: Section 2 reviews literature on land tenure security and climate adaptation. Section 3 examines land tenure systems and tenure policies in Ghana. Section 4 presents the methodology for the study. The results and discussions are presented in Section 5. Finally, section 6 is for conclusions and policy implications for the study.

2. BRIEF LITERATURE REVIEW

The implications of secure land tenure for smallholder investment in climate adaptation strategies have been recognised by policymakers and development economists. Using a randomized control trial, it has been acknowledged that smallholder farmers with secure land tenure invest in agroforestry and other climate adaptation measures in Zambia (Huntington & Shenoy, 2021). Secure land rights have a positive association with smallholder investment in climate-smart agricultural practices to combat land degradation in Nigeria (Shittu *et al*., 2018). However, the authors argued that farmers who access land through lease or communal land have a negative association with investment in climate-smart agricultural practices. Similarly, smallholder farmers with land transfer rights have a positive association with investment in crop rotation, manure application, and crop residue retention but a negative association with investment in agroforestry in Nigeria (Kehinde *et al*., 2022). This finding of the authors implies that smallholder farmers with secure land transfer rights have a higher probability of investing in selected sustainable land use practices.

Using panel data, a study demonstrated that land use and transfer rights incentivized smallholder farmers' investment in organic fertiliser application in China (Gao *et al*., 2017). Land use right duration has a positive association with investment in irrigation and water conservation structures among smallholder farmers in Vietnam (Vu & Goto, 2020). Land title registration has a positive association with investment in nine sustainable land use practices in Peru (Navarro-Castañeda *et al*., 2021). The authors argued that where local land governance functions well, land title intervention can complement traditional customary land rights, but not as a substitute. That is, land title intervention and customary land tenure rights should complement each other to strengthen smallholder farmers' land rights. In Malawi, sources of land tenure insecurity have a negative association with investment in soil conservation practices (Lovo, 2016). The study suggested that land tenure reform policy needs to be tailored towards formalizing land rental markets among smallholder farmers to address the insecure land tenure gap between land users and owners under customary land governance. Additionally, smallholder farmers in Liberia with secure land tenure are more likely to invest in tree crop plantations compared to those with insecure land tenure (Hadera *et al*., 2024).

In the context of Ghana, smallholder farmers who own land have a higher probability of investing in tree plantation, usage of animal manure, mulching, and chemical fertiliser (Abdulai *et al*., 2011). Smallholder farmers who operate in family farms and/ or practice sharecropping have less probability to invest in improved cocoa seedlings, fertiliser, and labour compared to those with land title registration (Donkor *et al*., 2023).

Therefore, the effect of secure land tenure on smallholder farmers' investment in sustainable agriculture is inconclusive. There could be several reasons for the variability of findings in the empirical studies. For instance, land tenure systems vary across countries, regions, districts, and even among tribes and families. These lead to inconsistent measurements of secure land rights. That is, using a single indicator to measure the effect of secure land tenure on investment in agriculture is not enough. While some studies define tenure security based on ownership duration, land property rights (land user, transfer, and exclusion rights), and perceive land tenure security, others employ land title registration. These concepts for measuring land tenure security are context-specific and shape smallholder adaptation behaviour differently. Also, sustainable agricultural practices among farmers are not one-size-fits-all, as investments in crop-switching, manure usage, chemical fertilizer usage, improved seed varieties, irrigation, agroforestry, and others may not respond uniformly in different land tenure rights.

This study contributes to knowledge by employing the multi-dimensional land tenure systems security to investigate their relationship with individual and intensity of climate adaptation strategies, using Multivariate probit and Poisson regression models.

3. THE STATE OF LAND TENURE SYSTEMS AND POLICIES IN GHANA

There are two major land tenure systems in Ghana, which are the statutory land rights (*de jure* land rights or land title registration) and customary land tenure rights (Azumah & Noah, 2023). Statutory land rights are rights that have been recognized and protected by law via statutes, acts, and regulations (Azumah & Noah, 2023; Josiah-Aryeh, 2008). This type of land tenure in Ghana can be acquired via the State Property and Contract Act, 1960 (CA

6), and the Land Statutory Act, 1963 (Act 186). That is, such land right is documented and registered with relevant authorities such as Ghana law courts and Land Secretariat, and this provided a clear and formal records of land ownership and/ or use. The characteristics of *de jure* land rights include formal land documentation, land registration, legal protection, and security of land ownership and use (Holland *et al*., 2022). This is the highest form of land tenure security, as there is legal recognition and protection of land ownership and use. Under this *de jure* tenure system, there are two types, which include freehold land rights and leasehold land ownership. While the freehold land right is the type of statutory land rights that provides absolutely land ownership and use, the leasehold land right provides temporary land ownership for a specific period of time (Abubakari *et al*., 2018). According to leasehold land rights under the de jure, non-Ghanaians can access land through a leasehold agreement up to 50 years. But a Ghanaian citizen can access and use a land under the leasehold agreement for 99 years and possibly renewal in the future (Azumah & Noah, 2023).

Furthermore, vested land under the statutory land ownership which about 2% of land in Ghana is a land tenure type that previously owned by traditional authorities and/ or communities and now vested in the state and administered for the benefit for the communities under the Land Administration Act 1962 (Act 123) S7 (Anaafo *et al*., 2023; Azumah & Noah, 2023). This tenure system provides some level of security to smallholder farmers, but they can lose their land rights anytime the government demands land for developmental projects for communities and the state. The worry is that smallholder farmers with vested land might be interested in investing in sustainable agricultural practices such as agroforestry, irrigation, organic fertilizer, and tree plantation. This is because the benefits of these practices accumulate over time.

Customary land tenure is the dominant (80%) in Ghana (Amanor, 2022), particularly in northern Ghana. For this customary land tenure, lands are controlled and managed by stools, chiefs, clans, families, kings, queen mothers, and/or fetish priests for the benefit of their members (Adjei-Poku *et al*., 2023; Amanor, 2008). These bodies of authorities manage and control land allocation, redistribution, use, and conflict resolution in communities. This customary tenure is characterized by communal ownership, where land is held in trust by traditional leaders on behalf of the community. The customary land tenure system is prevalent in northern Ghana for agricultural production. But the customary tenure has a lot of conflicts over land ownership and use in Ghana and other parts of West Africa (Edeh *et al*., 2022; Geyer, 2023). This is a disincentive for smallholder farmers to invest in sustainable agricultural practices and/or climate adaptation strategies. This implies that secure land rights for smallholder farmers to invest in climate adaptation strategies are weak under customary land tenure.

There are several land governance reform policies to enhance smallholder farmers' tenure security for better investment in sustainable agricultural farming in Ghana. The land tenure reform policies that enhance tenure security among smallholder farmers include the 1992 Constitution of Ghana, Land Administration Project (LAP), the Land Use and Spatial Planning Act (Act 925, 2016), and the Land Act and Customary Land Registration Act (2020) (Government of Ghana, 2020). The 1992 Constitution provides the foundation for land reforms in Ghana, promoting secure land tenure and property rights (Amanor, 2009). The National Land Policy (NLP), which was introduced in 1999, sought to strengthen land governance and encourage agricultural investment (Bugri, 2012).

In 2003, the Land Administration Project (LAP) was launched to complement the NLP by enhancing land administration efficiency (Quan *et al*., 2008). However, the LAP faced multiple challenges, including bureaucratic delays and coordination issues across land sector agencies (Cobbinah *et al*., 2020). Despite efforts to digitize land records under the LAP, most land administration processes remained manual, leading to inefficiencies (Quaye, 2020). Financial constraints further hindered the full implementation of the project, and the NLP failed to resolve all challenges in land governance, leading to the eventual cessation of the LAP after its second phase (Amanor, 2022).

To promote sustainable land use, the Land Use and Spatial Planning Authority was established. This authority oversees national, regional, and district-level planning to ensure decentralized development, equitable infrastructure distribution, and sustainable human settlements. The Customary Land Rights Registration Act of 2020 (Act 1036) was also introduced to improve transparency and accountability in land governance (Joannides, 2023; Kidido, 2024). This Act provides a framework for registering customary land rights, including agricultural lands.

The Land Title Registration Law aimed to make land titling the standard method for property registration in Ghana (Edwin *et al*., 2020). However, its implementation has been limited due to the continued dominance of traditional land governance practices (Jones-Casey & Knox, 2019). Nevertheless, land titling has become more common following recent land policy reforms, facilitating transactions such as leases, usufruct rights, mortgages, exclusivity rights, transferability rights, outright purchases, and sharecropping (Ghebru & Lambrecht, 2017). These systems of tenure security may have significant implications for farmers' climate adaptation strategies, which have not been extensively explored in the Ghanaian context.

4. DATA AND METHOD

4.1. Study context

The study was conducted in the five (5) Northern regions of Gahan. These regions include the Northeast, Savannah, Upper West, and Upper East regions of Ghana. These regions together account for approximately 42% of the country's total land area. There are about 20 major ethnic groups in the five northern regions (Mwakikagile, 2017). Land tenure arrangements and access to land for agriculture vary among these 20 tribes. Smallholder farmers in these regions are constrained by poor soil productivity coupled with climate change indicators such as high temperatures, erratic rainfall, and frequent droughts. Temperatures range from 14°C at night to 40°C during the day (Frimpong *et al*., 2014). It is also documented that the adoption rate of climate adaptation strategies is low among northern smallholder farmers (Asravor, 2022).

Agriculture is the backbone of the local economy, employing over 82% of the labour force. These regions are known as the food basket of Ghana due to the extensive cultivation of maize, soybeans, rice, groundnuts, cowpea, millet, sorghum, and yam (MoFA, 2022). The landscape consists of savanna vegetation, which the grassland interspersed with drought-resistant trees like baobab, acacia, and shea nut.

4.2. Sample Design

The data collection covered 52 districts and 198 Enumeration Areas (EAs) across the study area. The research is part of a broader initiative led by the Potsdam Institute for Climate Impact Research (PIK, Germany), the Leibniz Institute for Economic Research (RWI, Germany), the University for Development Studies (UDS, Ghana), and the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL, Burkina Faso). The project, titled "Decision support for strengthening land resilience in the face of global challenges (DecLaRe)", is funded by the Federal Ministry of Education and Research (BMBF, Germany). It aims to develop scalable recommendations for sustainable agricultural production in West Africa. A core objective of the DecLaRe project is to examine the linkage between land tenure rights and agricultural production, using a household survey in Northern Ghana.

The study used a structured household questionnaire covering key modules such as employment (agriculture, non-agriculture business, and wage), land tenure rights (perceived tenure security, land use duration, land transfer right, land use right, and land exclusion right), crop and livestock production (inputs use and quantities, expenditures), climate adaptation strategies, sources of income, access to agricultural and financial services, food security, and household expenditures. However, for this study, only data related to land tenure systems security and climate adaptation strategies were analysed.

A three-stage sampling procedure was employed: (1) Purposive sampling to select the study area; (2) Probability proportional to size sampling to draw rural primary sampling units (PSUs) in each of the five regions; and (3) Random selection of 25 households from each PSU. The initial sample size included 2,970 households, but after data cleaning and eliminating inconsistent responses, the final sample comprised 2,934 households. Data was collected between November and December 2023, using Computer-Assisted Personal Interviewing (CAPI).

4.3. Descriptive statistics

The study operationalized key variables of interest, particularly the land tenure systems, security, and climate adaptation strategies. Perceived land tenure security is widely used in regions where customary land tenure systems dominate. According to the Prindex report, perceived tenure security reflects how individuals or communities assess the safety of land rights, which can differ from formal legal ownership (Prindex, 2024). To measure tenure security, a four-point Likert scale was used to assess household concerns over potential land loss. Responses were regrouped into a binary variable: 1 = Secure tenure (low concern), 0 = Insecure tenure (high concern). Other land-related rights, such as land transfer, land use, and land exclusion rights, were measured as binary variables, while land ownership duration was measured in years.

The descriptive results of the smallholder farmers are presented in Table 1. The adoption of climate adaptation strategies among households was relatively low. The most common strategies included fertilizer application, adopted by 47% of households, intercropping at 24%, and crop-switching at 21%. Manure usage was employed by 13% of respondents, improved seed varieties by 12%, and irrigation also by 12%. Only 7.6% of households practiced agroforestry. Approximately 67.7% of farm households perceived their land tenure rights as secure, while about 32% reported tenure insecurity. Furthermore, about 60% had land transfer rights, 84% had land use rights, and 68% had land exclusion rights.

Other socioeconomic findings reveal that 83% of households were male-headed, with an average head age of 46 years. About 22% of household heads had formal education, and the average household size was five members. Access to agricultural extension services was limited, with only 12% of households reporting access, while climate information was available to just 18%. Membership in Farmer-Based Organizations (FBOs) was also low, with only 8% of households participating. The average homestead-to-farm distance was 5.8 km, and the average farm size under cultivation was 3 hectares.

4.4. Data Analytical Strategy

To analyse the effect of secure land tenure rights on climate adaptation, the study employed the Multivariate Probit (MVP) Model and the Negative Binomial Poisson Regression (NBPR) Model. The Multivariate probit, as outlined by (Czado, 2000), is suitable for analysing multiple, interdependent binary outcomes. Since farmers adopt multiple adaptation strategies simultaneously, using separate binary probit models would lead to estimation inefficiencies. The MVP model accounts for the correlation among adaptation choices and estimates joint probabilities, yielding more robust insights into how secure land tenure rights and socioeconomic factors influence adaptation decisions. The model specification follows:

Table 1: Variable measurement and descriptive statistics

Variable	*Description*	*Measurement*	*Mean*	*Std. dev*
Tenure system security				
Tenure security	Households fear losing at least one parcel of land in the next five years	1. Yes, 0. Otherwise	0.323	0.468
Land transfer right	Household has the right to transfer at least one plot of their land	1. Yes, 0. No	0.603	0.489
Land use rights	A household has the use right over at least one of its plots:	1. Yes, 0. No	0.839	0.368
Land exclusion right	Household has the right to exclude other people from using at least one of their plots	1. Yes, 0. No	0.684	0.465
Land duration	The average number of years a household has used at least one of the plots	Years	13.227	12.565
Adaptation strategies				
Crop-switching	A household changed crop variety for production in the past 12 months	1. Yes, 0. No	0.207	0.405
Improved seed varieties	A household used improved crop varieties implemented in the past 12 months	1. Yes, 0. No	0.116	0.320
Intercropping	A household practices intercropping implemented in the past 12 months	1. Yes, 0. No	0242	0.428
Agroforestry	A household practices an alley and strip farming system implemented in the past 12 months	1. Yes, 0. No	0.076	0.266
Inorganic fertilizer	A household used chemical fertilizer in the past 12 months	1. Yes, 0. No	0.472	0.499
Organic manure	A household used animal/livestock manure in the past 12 months	1. Yes, 0. No	0.135	0.428
Irrigation	A household implemented irrigation in the past 12 months	1. Yes, 0. No	0.117	0.321
Socioeconomic variables				
Age	Household head age	Years	46.265	15.447
Gender	Gender of the household head	1. Male, 0. Female	0.833	0.373
Education	A household head has access to education	1. Yes, 0. No	0.219	0.414
Household size	Total number of family members in the house for the past 6 months	Number	5.124	2.457
Extension	At least one family member has access to extension services	1. Yes, 0. No	0.124	0.329
Rist attitude	Are you generally a person who is fully prepared to take risks	Scale: 0-10 (0 not willing and 10 very willing)	5.936	2.400
FBO membership	At least one of the household members belongs to a Farmer-Based Organisation	1. Yes, 0. No	0.081	0.273
Distance (km)	Homestead distance to farmland	Km	5.781	108.088
Climate information	At least one of the household members accesses climate change information services	1. Yes, 0. No	0.179	0.384
Rainfall intensity	A household's perception of rainfall for the past five years	1. Decreased, 0. Otherwise		
Rainfall perception	A household head perceived that annual rainfall has decreased for the past five years	1. Yes, 0. Otherwise		
Farm area	Average total farm size under cultivation	Hectares	2.970	4.968
Northern region	A household in the northern region	1. Yes, 0. Otherwise	0.316	0.465
Upper East	A household is in the Upper East region	1. Yes, 0. Otherwise	0.194	0.395
Savannah	A household in the Savannah region	1. Yes, 0. Otherwise	0.111	0.315
Upper West	A household is in the Upper West region	1. Yes, 0. Otherwise	0.270	0.444
Northeast	A household in the Northeast region	1. Yes, 0. Otherwise	0.109	0.312

Source: DecLaRe Ghana household survey 2023.

$$Y_{ij}^{*} = x_{ij}^{'}\delta_j + \varepsilon_{ij} \quad (1)$$

where the Y_{ij}^{*} denotes the latent variable for farmers i^{th} practicing j^{th} alternative adaptation strategies. The x_{ij} denotes the land tenure systems security and other socioeconomic factors for farmers (i) practicing climate adaptation strategies (j); the δ_j denotes the parameters to be estimated for each adaptation strategy; and the ε_{ij} is the random error term, which is assumed to be multivariate normally distributed. The self-reported observed binary outcomes $\left(Y_{ij}^{*}\right)$ are related to the latent variables as follows:

$$Y_{ij} = 1 \; if \; Y_{ij}^{*} > 0 \; and \; Y_{ij} = 0 \; otherwise \quad (2)$$

This model allows for the simultaneous estimation of multiple correlated binary outcomes while accounting for the potential correlation between the error terms of different equations.

For analysing adaptation intensity, the NBPR model is ideal when the dependent variable is a count measure (Cameron & Trivedi, 2013; Morales-Navarrete *et al*., 2024). The Poisson model assumes that the mean and variance are equal, but when overdispersion is present (i.e., variance exceeds the mean), the NBPR model is preferred as it introduces an additional dispersion parameter to correct variance issues (Ren *et al*., 2025). The model specification follows:

$$E\left(Y_{ij} \mid X_{ij}\right) = \lambda_{ij} = \exp\left(x_{ij}^{'}\beta_j\right) \quad (3)$$

Where Y_{ij} denotes the count-dependent outcome variable for farmers (i) for the x_{ij} observation. The x_{ij} is vector of land tenure systems security and other socioeconomic factors, and the β_j is the vector of coefficients to be estimated. The probability mass function of the Negative Binomial distribution can be expressed as:

$$p\left(Y_{ij} = y_{ij} \mid x_{ij}\right) = \left[\mu^{y_{ij}}\Gamma\left(y_{ij}+\alpha\right)\left(1/\alpha+\mu\right)\right)^{y+\alpha}\Big] \Big/ y! \; (\alpha)\Gamma(\alpha).(1/\alpha)^{\alpha} \quad (4)$$

Where the α is the over-dispersion parameter and Γ is the Gamma function, which generalizes the factorial function to non-integer values. This negative binomial model is known as the Negbin 2 type, and its parameters are determined by using the maximum likelihood approach (Gurmu & Trivedi, 1996). The log-likelihood function can be expressed as:

$$\ln L_{ij} = \ln \Pr\left(Y_{ij} = y_{ij}\right) = \sum_{n=0}^{y_{ij}-1} \ln\left(\alpha + n\right) - \ln y_{ij}! + y_{ij}\ln\left(1-\theta\right) + \alpha \ln \theta_{ij} \quad (5)$$

Where $\theta_{ij} = \alpha/_{\alpha+\mu_{ij}}$. Note that if $\theta_{ij} > 0 \; and \; \alpha > 0$ then, it means that the variance is greater than the mean (Rivera *et al*., 2015).

5. RESULTS AND DISCUSSIONS

5.1. Land tenure systems' security association with climate adaptation strategies

Table 2 illustrates the results of the correlation between land tenure systems security with various climate adaptation strategies. The Wald test of the MVP model is significant (Wald $Chi^2(147)$ =2822.43; Prob > Chi^2 =0.0000), and the Likelihood ratio test is also significant ($Chi^2(21)$ = 1054.95; Prob > chi2 = 0.0000). The diagnosis of the model indicates that the MVP model provides a robust estimate.

The four systems of tenure security employed for the study have different directions of correlation with individual climate adaptation strategies. The study reveals that perceived land tenure security has a significant positive correlation with crop-switching, improved seed, organic manure, agroforestry, and irrigation. This implies that smallholder farmers with perceived secure land rights are more likely to invest in these climate adaptation strategies. That is, smallholder farmers who feel secure in their land rights are more likely to make sustained investments in land management, while those facing tenure insecurity may be reluctant to do so.

Land use right has a positive and statistically significant correlation with inorganic fertilizer, organic manure, and agroforestry, all at the 1% level. This implies that smallholder farmers with land use rights are more likely to adopt these adaptation strategies compared to their counterparts (Adeagbo *et al*., 2023). Besides, land exclusion right reveals a positive and significant correlation with crop-switching, improved seed varieties, and irrigation, while showing a negative correlation with organic manure and inorganic fertilizer at various levels of significance. Thus, smallholder farmers with stronger land exclusion rights are more likely to invest in adaptation strategies such as inorganic fertilizer, organic manure, and agroforestry. However, weaker land exclusion rights are associated with lower investment in organic manure and inorganic fertilizer. This is plausible for organic manure since its benefits accrue for a long time. Therefore, smallholder farmers who are uncertain about their land exclusion rights may be reluctant to invest in long-term adaptation strategies in the changing climate.

Moreover, it reveals that land transfer rights have positively correlated with inorganic fertilizer, organic manure, intercropping, agroforestry, and irrigation, while negatively correlated with improved seed only. This suggests that smallholder farmers with strong land transfer rights are more willing to invest in agroforestry and irrigation but may be less likely to invest in improved seed varieties. Improved crop varieties have a short-term benefit to smallholder farmers compared to irrigation and agroforestry. For this reason, smallholder farmers with less secure land transfer rights will be interested in investing in improved seeds than in agroforestry.

However, the number of years a smallholder farmer has owned a particular piece of farmland has a negative and significant correlation with improved seeds and agroforestry at 1% and 10% levels, respectively. This finding is thought-provoking, as longer land ownership of a parcel of farmland leads to lower farmers' decision to invest in improved seeds and agroforestry. This contradicts land property rights theory, which postulated that land ownership enhances farmers' investment decisions in yield-enhancing agricultural practices (Abdulai *et al*., 2011; Abdulai & Ochieng, 2017; Kehinde *et al*., 2021). This finding could be attributed to several factors, such as the traditional farming systems being deeply rooted among long-term landownership, farmers' risk aversion to new or improved farming methods, as well as differences in access to extension services among farmers.

These findings align with several previous studies. For example, a study revealed that smallholder farmers with secure land tenure invest in sustainable land management practices in Ethiopia(Adam *et al*., 2023). Similarly, in Southern Africa, secure land rights promote sustainable land management practices at the plot level (Oduniyi, 2022). In Kenya and Burkina Faso, found that formal land lease agreements and intra-household tenure arrangements increased farmers' likelihood of investing in land management (Stiem-Bhatia *et al*., 2022). Conversely, weak land tenure systems have been linked to poor land management practices (Azadi *et al*., 2021). Another researcher found that customary land tenure systems negatively affected land restoration practices (Owino, 2021). These empirical findings underscore the importance of land tenure systems security in promoting climate adaptation strategies. Strengthening land rights could serve as a vital policy instrument for enhancing climate resilience and ensuring sustainable agricultural productivity in vulnerable regions.

The socioeconomic variables considered in this study exhibit varying significant correlations with the climate adaptation strategies. The sex of a smallholder farmer has a significant positive correlation with inorganic fertilizer only at a 1% level. This means that male smallholder farmers are more likely to invest in inorganic fertilizer compared to female smallholder farmers. Age showed a positive correlation with improved seed at a 1% significance level. This shows that older smallholder farmers are more likely to invest in improved seed compared to young farmers. However, the study reveals that age has a negative correlation with crop-switching, inorganic fertilizer, and intercropping at various significance levels. Thus, younger farmers are more likely to invest in these climate adaptation strategies than older farmers. Formal education is positively correlated with inorganic fertilizer and improved seed but negatively correlated with intercropping

Table 2: Covariate association with climate adaptation strategies

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	*Crop-switching*	*Fertiliser*	*Manure*	*Improved seeds*	*Intercropping*	*Irrigation*	*Agroforestry*
Land tenure security systems							
Perceived tenure security	0.358***	-0.011	0.270***	0.243***	0.008	0.433***	0.396***
	(0.036)	(0.027)	(0.047)	(0.039)	(0.031)	(0.044)	(0.044)
Land use duration	0.005	-0.001	0.001	-0.012***	0.005	-0.004	-0.008*
	(0.004)	(0.003)	(0.004)	(0.004)	(0.003)	(0.004)	(0.004)
Land use rights	-0.163	0.549***	0.951***	-0.217	-0.001	0.384	0.697***
	(0.166)	(0.118)	(0.200)	(0.170)	(0.144)	(0.262)	(0.243)
Land exclusion right	0.887***	-0.406***	-0.499***	0.776***	0.126	0.390**	-0.372**
	(0.111)	(0.080)	(0.126)	(0.124)	(0.091)	(0.172)	(0.173)
Land transfer right	-0.016	0.036**	0.078***	-0.086***	0.048***	0.104***	0.175***
	(0.020)	(0.016)	(0.027)	(0.022)	(0.018)	(0.026)	(0.033)
Socioeconomic factors							
Age	-0.008***	-0.004**	-0.000	0.010***	-0.005**	-0.001	0.001
	(0.003)	(0.002)	(0.003)	(0.003)	(0.002)	(0.003)	(0.004)
Education	0.074	0.145**	0.079	0.251***	-0.120*	0.055	0.081
	(0.081)	(0.063)	(0.099)	(0.082)	(0.073)	(0.109)	(0.111)
Sex	0.103	0.298***	0.154	0.139	0.096	0.166	0.089
	(0.095)	(0.071)	(0.110)	(0.105)	(0.082)	(0.118)	(0.117)
Family size	0.033**	0.050***	0.004	0.036***	0.055***	0.025	-0.040
	(0.014)	(0.010)	(0.020)	(0.014)	(0.013)	(0.021)	(0.025)
FBO membership	-0.016	0.270***	-0.458***	0.492***	-0.427***	-0.116	-0.375**
	(0.123)	(0.096)	(0.163)	(0.115)	(0.121)	(0.143)	(0.182)
Extension	0.157	0.295***	0.495***	0.446***	0.125	0.430***	0.363***
	(0.103)	(0.084)	(0.123)	(0.101)	(0.096)	(0.112)	(0.127)
Distance	-0.018	0.063*	-0.302***	0.083	-0.133**	-0.195***	-0.314***
	(0.044)	(0.038)	(0.067)	(0.053)	(0.052)	(0.071)	(0.082)
Farm area	-0.008	0.020***	-0.002	0.011*	-0.015*	-0.008	-0.025
	(0.009)	(0.008)	(0.009)	(0.006)	(0.008)	(0.007)	(0.016)
Climate information	1.692***	-0.109**	1.933***	0.181**	1.298***	1.371***	1.470***
	(0.070)	(0.054)	(0.132)	(0.073)	(0.062)	(0.106)	(0.102)
Rainfall perception	0.133	0.196***	0.273**	0.370***	-0.081	-0.102	-0.135
	(0.088)	(0.065)	(0.138)	(0.096)	(0.076)	(0.123)	(0.123)
Rain-intensity perception	0.327***	-0.181***	0.252**	-0.002	0.370***	0.190	0.241**
	(0.092)	(0.060)	(0.123)	(0.091)	(0.075)	(0.116)	(0.123)
Risk attitude	-0.025	-0.019*	0.024	0.074***	-0.003	0.080***	0.066***
	(0.016)	(0.011)	(0.022)	(0.017)	(0.013)	(0.023)	(0.023)
Northern	0.392***	0.208**	-0.460**	0.226*	-0.815***	-0.157	-1.154***
	(0.124)	(0.089)	(0.196)	(0.117)	(0.109)	(0.243)	(0.207)
Upper East	0.233*	0.642***	-0.207	-0.085	-0.167	0.252	-0.508***
	(0.136)	(0.093)	(0.202)	(0.125)	(0.104)	(0.237)	(0.181)
Northeast	-0.653***	0.247**	0.290	-1.603***	-0.075	-0.110	-2.935***
	(0.241)	(0.111)	(0.237)	(0.310)	(0.128)	(0.314)	(0.281)
Upper West	0.524***	0.471***	0.969***	-0.226*	0.123	1.055***	0.155
	(0.144)	(0.097)	(0.195)	(0.136)	(0.106)	(0.232)	(0.170)
Constant	-3.315***	-0.980***	-4.143***	-3.753***	-1.281***	-4.987***	-3.350***
	(0.269)	(0.189)	(0.369)	(0.298)	(0.219)	(0.372)	(0.355)
Model summary							
Observations =	2934						
Wald Chi² (147) =	2822.43						
Prob > Chi² =	0.0000						
Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho71 = rho32 = rho42 > = rho52 = rho62 = rho72 = rho43 = rho53 = rho63 = rho73 = rho54 = rho64 = rho74 = rho6> 5 = rho75 = rho76 = 0: chi2(21) = 1054.95 Prob > chi2 = 0.0000							

Source: DecLaRe Ghana household survey 2023. Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

systems. This suggests that educated smallholder farmers are more likely to invest in these strategies but less likely to invest in an intercropping system.

Land area was found to be a key determinant of climate adaptation, as the study reveals that farm size has a positive and significant correlation with inorganic fertilizer and improved seed but a negative correlation with intercropping at various significance levels. These suggest that smallholder farmers with large parcels of land for crop cultivation are more likely to invest in inorganic fertilizer and improved crop varieties, but less likely to invest in intercropping. This is intuitively and economically good as smallholder farmers with small parcels of land practice sustainable intensification agriculture to sustain soil fertility and maximise yield. On the other hand, smallholder farmers with large parcels of land engage in agricultural expansion instead of intensification practices. This finding aligns with previous empirical studies (Thinda *et al*., 2020; Yegbemey, 2021).

Behavioural factors like smallholder farmers' ability to take risks play a critical role in adaptation strategies in the changing climate. The study reveals that smallholder farmers' risk attitude is positively correlated with improved seed, irrigation, and agroforestry but negatively correlated with inorganic fertiliser at various levels of significance. These indicate that as smallholder farmers' ability to take risks increases, they are more likely to practice these climate adaptation strategies. This finding underscores the importance of risk tolerance for enhancing smallholder farmers' ability to adopt plot-level climate strategies to boost farm productivity. For instance, irrigation requires significant upfront investment, but risk-loving farmers may be more willing to adopt irrigation systems due to their long-term economic benefits. These findings align with studies (Mulungu *et al*., 2024; Patil & Veettil, 2024; Roussy *et al*., 2017) that farmers' risk preferences influence their ability to invest in sustainable land management practices in the global south. Contrariwise, the negative correlation of risk attitude with inorganic fertiliser may hint at an emerging awareness among risk-tolerant farmers of potential long-term soil degradation or environmental downsides associated with their overuse (Nath *et al*., 2023; Pahalvi *et al*., 2021; Saha *et al*., 2024).

Access to agricultural extension services exhibits a positive and significant correlation with inorganic fertilizer, organic manure, improved seed, irrigation, and agroforestry. This suggests that smallholder farmers with access to extension services are more likely to adopt these practices to enhance soil fertility and land productivity. Agricultural extension service is one of the relevant policy indicators that is crucial for the dissemination and diffusion of farming innovation information. Particularly, extension bridges the gap between policymakers and farmers for innovative farming technologies, thereby promoting sustainable land management practices. It has been demonstrated that access to agricultural extension services is a critical pathway for sustainable agrifood systems in rural African settings. This finding is consistent with previous research (Danso-Abbeam *et al*., 2018; Olumba *et al*., 2025; Thapa & Dhakal, 2024).

Moving forward, climate information service positively correlates with crop-switching, organic manure, improved seed, irrigation, and agroforestry at different levels of significance. This suggests that smallholder farmers with access to climate information services are more likely to adopt strategies in the changing climate. Climate information services enhance smallholder farmers' access to climate change indicators timely manner to help them plan farming effectively. This finding corroborates with other studies in Africa (Diro *et al*., 2022; Djido *et al*., 2021; Warner *et al*., 2022). Also, perception of rainfall intensity has a positive correlation with crop-switching, manure, intercropping, and agroforestry, but a negative correlation with inorganic fertilizer. That is, a smallholder farmer who perceived that rainfall intensity decreased is more likely to invest in these climate adaptation strategies. Likewise, smallholder farmers who perceived a decline in annual rainfall volume over the past five years were more likely to use inorganic fertilizer, organic manure, and improved seed.

5.2. Complementarity and substitutability adaptation strategies

Table 3 presents the estimates of the correlation matrix for climate adaptation strategies under study. The correlation coefficients determine the complementarity and substitutability of the adaptation strategies. It is important to note that if a coefficient is positive, then the interaction terms of such strategies are complementary, and if negative coefficient, then it signifies a substitute. By general observation, the study reveals that almost all the climate adaptation strategies are complementary, as many of the correlation coefficients are positive and statistically significant at the 1% level. This indicates that smallholder farmers can maximize land productivity by adopting multiple climate adaptation strategies simultaneously at the plot level. The synergies among these strategies optimize resource efficiency, enhancing overall effectiveness by generating greater benefits when implemented together rather than in isolation. Adoption of multiple adaptation strategies has the potential to reduce smallholder farmers' risks in the changing climate and its impact on agriculture.

Studies have shown that adopting several climate adaptation strategies increases benefits in terms of farm productivity, reduction of labour cost, and increasing incomes among smallholder farmers (Baninla *et al*., 2022; Eisenack & Stecker, 2012; Tetteh, 2023). Therefore, policymakers need to prioritize and design integrated climate adaptation programs that encourage farmers to adopt multiple strategies. For fostering a comprehensive and coordinated adaptation policy intervention, such programs can significantly enhance climate resilience, improve agricultural productivity, and ensure long-term sustainability of agrifood systems.

4.3. Tenure systems' security association with climate adaptation strategies intensity

To complement the above estimates, the study further examines the different land tenure securities and their correlation with climate adaptation intensity. The results are presented in Table 4. The study reveals that the goodness of fit for the Poisson model is significant at

Table 3: Synergies and trade-offs of CCAS

Interaction terms	*Coefficient*	*Std. Err.*	*z*	*p>|z|*
Chemical fertilizer*crop-switching	0.050	0.036	1.41	0.159
Manure*crop-switching	0.506***	0.042	12.00	0.000
Improved seed*crop-switching	0.099**	0.047	2.11	0.035
Intercropping*crop-switching	0.505***	0.034	14.78	0.000
Irrigation*crop-switching	0.669***	0.042	16.08	0.000
Agroforestry*crop-switching	0.610 ***	0.038	16.06	0.000
Manure*chemical fertilizer	-0.061	0.048	-1.26	0.208
Improved seed*chemical fertilizer	0.252***	0.040	6.25	0.000
Intercropping*chemical fertilizer	0.001	0.034	0.03	0.972
Irrigation*chemical fertilizer	-0.023	0.051	-0.45	0.651
Agroforestry*chemical fertilizer	-0.085*	0.046	-1.85	0.065
Improved seed*manure	0.062	0.053	1.17	0.242
Intercropping*manure	0.476***	0.037	12.84	0.000
Irrigation*manure	0.647***	0.038	16.94	0.000
Agroforestry*manure	0.712***	0.038	18.87	0.000
Intercropping*improved seed	-0.036	0.042	-0.86	0.392
Irrigation*improved seed	0.190***	0.059	3.24	0.001
Agroforestry*improved seed	0.176***	0.056	3.16	0.002
Irrigation*intercropping	0.601***	0.041	14.72	0.000
Agroforestry*intercropping	0.576***	0.045	12.76	0.000
Agroforestry*irrigation	0.872***	0.021	41.97	0.000

Source: DecLaRe Ghana Household Survey 2023.

1% level [(Goodness-of-fit = 9919.411; Prob > Chi² (2912) = 0.0000)]. This implies that there is overdispersion in the data. To account for the overdispersion, the Negative Binomial Poisson Regression (NBPR) model was employed. The significance of the Likelihood Ratio test of the alpha coefficient demonstrates that the NBPR model is the best fit for the estimation. Similarly, the AIC and BIC estimated values confirm that the NBPR model is the best fit for the analysis. Therefore, the results of the NBPR model are discussed.

Based on the NBRP results, perceived land tenure security, land use right, and land exclusion right have a positive and significant correlation with the intensity of climate adaptation strategy adoption

Table 4: Estimates of land tenure rights effects on climate adaptation intensity

Variable	*Standardized Poisson*		*Negative binomial Poisson regression*	
	Coefficient	*Std. Err.*	*Coefficient*	*Std. Err.*
Land tenure security systems				
Perceive tenure security	0.229***	0.011	0.207***	0.026
Land use duration	0.002*	0.001	-0.000	0.002
Land use rights	0.158***	0.059	0.263**	0.114
Land exclusion rights	0.478***	0.039	0.545***	0.080
Land transfer rights	-0.003	0.007	0.007	0.015
Socioeconomic factors				
Age	-0.003***	0.001	-0.003	0.002
Education	0.046*	0.027	0.059	0.060
Gender	0.017	0.032	0.054	0.066
Household size	0.047***	0.005	0.075***	0.010
FBO membership	-0.137***	0.040	-0.111	0.088
Extension	0.300***	0.032	0.341***	0.076
Distance	-0.050***	0.017	-0.105***	0.036
Farm area	-0.008***	0.003	-0.013**	0.005
Climate information	1.429***	0.024	1.567***	0.051
Rainfall perception	0.060*	0.032	-0.058	0.066
Rainfall intensity perception	0.321***	0.033	0.442 ***	0.065
Risk attitude	0.034***	0.006	0.043***	0.011
Northern	-0.177***	0.044	-0.444***	0.087
Upper east	0.039	0.046	-0.132	0.091
Northeast	0.011	0.059	-0.118	0.111
Upper West	0.456***	0.046	0.292***	0.094
Constant	-1.310***	0.093	-1.471***	0.188
Model Summary				
Observations =	2,934			
LR chi²(21) =	5885.84			
Prob > chi² =	0.0000			
Pseudo R² =	0.2991			
Log likelihood =	-6897.9371			
Deviance goodness-of-fit =	8388.609			
Prob > chi²(2912) =	0.0000			
Pearson goodness-of-fit =	9919.411			
Prob > chi2(2912) =	0.0000			
Alpha			0.988***	0.047
LR test of alpha=0:			Chibar²(01) = 2427.55; Prob >= Chibar² = 0.000	
AIC	13839.87		11414.33	
BIC	13971.52		11551.96	

Source: DecLaRe Ghana household survey 2023: Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1 represents 1%, 5%, and 10% significance levels, respectively.

at 1% level. This finding implies that smallholder farmers with strong, secure land rights are more likely to adopt multiple climate adaptation strategies simultaneously compared to their counterparts. Empirical studies demonstrate similar findings. For instance, in Togo, a study reveals that tenure security positively influenced household climate adaptation strategies (Kossigan & Edgeweblime, 2023). Similarly, land tenure security incentivises farmers' adaptive capacity in response to climate change in Colombia (Castro & Kuntz, 2022). It has been argued that secure land use rights are essential for fostering climate strategies' adaptation (Molua *et al.*, 2023). Land exclusion rights empower landowners to implement climate adaptation measures without external interference (Landesa, 2020).

Other factors that correlate with climate adaptation strategies include household size, extension service, access to climate information, rainfall intensity perception, and risk attitude of smallholder farmers. The implication is that these socioeconomic factors are pathways for promoting climate adaptation at the plot level. The findings offer valuable guidance for policymakers, highlighting the need to strengthen land rights and tenure security policies while also enhancing access to socioeconomic resources that support adaptation efforts. These findings are corroborated by other studies in developing economies (Assaye *et al.*, 2023; Legesse *et al.*, 2024; Nonvide, 2021).

6. CONCLUSIONS AND POLICY IMPLICATIONS

This study investigates the land tenure systems' security and adaptation strategies nexus in the changing climate in Northern Ghana. The MVP and NBPR models were employed for the estimates of 2,934 in the study setting. The study demonstrates that the correlation between land tenure systems of securities and adaptation strategies is heterogeneous. Smallholder farmers with perceived land tenure security are more likely to adopt crop variety switching, organic manure, improved crop seeds, irrigation, and agroforestry. Smallholder farmers with long land use duration and less likely to adopt improved crop seeds and agroforestry. The probability of adopting inorganic fertiliser, organic manure, and agroforestry is high among smallholder farmers with land use rights. Farmers with land exclusion rights are more likely to adopt crop variety-switching, improved seeds, and irrigation, but less likely to adopt inorganic fertiliser, organic manure, and agroforestry. In terms of land transfer rights, farmers with secure tenure via land transfer rights are more likely to adopt inorganic fertiliser, organic fertiliser, intercropping, irrigation, and agroforestry, but less likely to adopt improved seeds. Furthermore, farmers with perceived land tenure security, land use, and exclusion rights are likely to adopt multiple climate adaptation strategies. However, land use duration and transfer rights do not have a significant correlation with climate adaptation intensity.

The study conclude that different land tenure security has different influence on climate adaptation strategies. While others encourage climate adaptation strategies, others disincentive adaptation strategies which have policy implications.

Therefore, interventions by governments and other policymakers should develop context-specific land tenure policies that reflect local socio-economic realities. Using a one-size-fits-all land tenure security policy may yield inconsistent outcomes. The strong correlation between adaptation intensity and land tenure systems security highlights the need for integrated land reform policy interventions. Fostering synergies between land tenure policies and agricultural adaptation programs will create a more resilient farming sector. Hence, governments and development partners should align land reform policies with climate resilience initiatives, ensuring that land tenure reforms support long-term adaptation investments. Finally, the study recommends that future studies should develop a land tenure security index to measure its effect on climate adaptation strategies, since different tenure systems have different effects on adaptation strategies.

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Ethical approval: Ethical review and approval were waived for this study because of the study not involving human clinical trials or animal experimental trials, and participation for all respondents for the data collection was voluntary. This research was approved and supervised by the Ghana Statistical Service, whose mandate is to conduct surveys with a code of ethics and practice to ensure the relevance, accuracy, reliability, and integrity of statistics. Hence, all respondents' consent was sought before the interviews were conducted.

Data Availability: The data employed for this study are available upon request. The data is not publicly available to protect the personal privacy of farm households based on DecLaRe Project Data Protection terms.

Conflict of interest: The authors declare no conflict of interest.

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