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Climate-smart agriculture adoption in rural Ghana: do resource requirements matter?

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Abstract

Background To create resilient food systems and agriculture against climate change and variability, farmers are urged to implement climate-smart agriculture (CSA). Despite its promotion by governments and development agencies, the resource requirements of CSA practices continue to keep smallholder farmers in Ghana from adopting them at a high rate. This study developed a typology for categorising CSA practices under their dominant resource requirements in Ghana's Sudan Savannah agroecological zone.

Methods We use data collected from 350 smallholder farmers in seven communities of the North East and Upper East Regions of Ghana to achieve the main aim of the study. We categorised 12 CSA practices under three main resource requirements, i.e., labour, land and finance to develop our CSA typologies. We further employed the multivariate probit and the multivariate ordered probit models to examine the factors that influence the adoption decision of smallholder farmers within each CSA typology.

Results Our results show the three typological categories of CSA practices as: (1) land-intensive practices, (2) labour-intensive practices, and (3) finance-intensive practices. We find that institutional factors such as access to extension services, land tenure security, access to input markets and climatic shocks influence the likelihood and extent of adoption of the various resource-based typologies of CSA practices with gender disparities. Our estimation showed that while gender played no role in the adoption of both land- and labour-intensive practices, it was a major determinant in the adoption of finance-intensive practices with female farmers being less likely to adopt finance-intensive CSA practices. We again find that behavioural factors, particularly subjective norms which measures the effect of social pressure on adoption behaviour reduced the likelihood of adopting finance-intensive practices among males. Finally, the district fixed effects in our estimation shows that farmers in the more urbanised districts had a higher likelihood of adoption than those in the more rural districts.

Conclusion While different CSA practices have different resource requirements, farmers are willing to adopt multiple practices to maximize their synergistic effect. Policymakers must ensure access to farm inputs and extension services, and develop secure land tenure regimes that encourage investment in CSA practices by smallholder farmers.

Keywords Climate change adaptation, Climate-smart agriculture, Adoption, Food security, Gender

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Introduction

The detrimental effects of climate variability and change threaten the agro-based livelihoods of millions of people in sub-Saharan Africa (SSA) [1]. Risks associated with climate change include decreased agricultural yields, increased food and nutrition insecurity, and a general decline in population welfare in the SSA region. These risks have an adverse impact on the achievement of regional and global targets like the Sustainable Development Goals and Africa Agenda 2063 [2]. High levels of poverty, inadequate institutional and structural frameworks, and poor uptake of contemporary agricultural production systems are the contexts in which climate risks are embedded [3].

A large portion of Ghana's rural labour force, around 60% of whom work in agriculture, is vulnerable to the effects of climate change [4, 5]. Climate projections in Ghana indicate that the country will experience an increase in extreme weather events such as droughts, while the temperature is expected to rise by 3.9^{0}C and rainfall decrease by 18.8% by 2080 across all the agroecological zones of the country [6]. These projections pose a threat to the millions of households in Ghana who rely on agriculture as their major source of income and livelihoods. This necessitates the need for adaptation measures within the agricultural sector of Ghana to build the resilience of farming households and communities.

Governments and international development organizations continue to promote climate-smart agriculture (CSA) as a way to mitigate the negative effects of climate change on agriculture. CSA is defined as consisting of a set of agricultural practices that aim to sustainably increase the productivity of agricultural production systems, build resilience and simultaneously reduce emissions to achieve food security and development goals [7]. CSA has the aim of achieving its tripartite pillars of (1) sustainably increasing agricultural productivity to achieve increased farm income and food security, (2) building the resilience of agricultural systems to the effects of climate change and variability and (3) reducing and/or eliminating the emission of GHGs from agricultural activities where possible [7, 8].

The National Climate-Smart Agriculture and Food Security Action Plan, which aims to facilitate and operationalize the integration of climate change into the food and agriculture sector development plans and programs of Ghana, has been used by successive governments of Ghana to promote CSA [9]. Despite these efforts from the Government of Ghana and its donor partners, CSA adoption among smallholder farmers in Ghana continues to be low [10].

The low adoption of CSA practices may be attributed to the significant investment in land, labour and financial capital required by smallholders in dryland farming systems in developing countries [8, 11, 12]. Lack of access to land, labour, or finance hinders the adoption of CSA practices when these resources are needed in greater quantities [11]. Again, there are gender differentials in the adoption of CSA practices, which may be attributable to the gender-specific constraints smallholder farmers face in sub-Saharan Africa [13–16].There is a plethora of studies on CSA adoption in SSA [17–19] and in Ghana [10, 20–22], however, these studies do not provide a clear conceptual understanding of farmers' adoption process [23]. Although broader frameworks for the characterisation and analysis of CSA exist [7, 24], they do not explain the adoption of CSA practices under different resource requirements [12, 25]. Indeed, there are limited studies that have examined the adoption of CSA practices among smallholder farmers in rural Ghana, particularly in the context of resource requirements. This paper addresses this gap by adapting the typologies of [12] and [25] to categorise CSA practices based on the required resources for their adoption. We also analyse the adoption of CSA practices by smallholder farmers in Ghana's Sudan Savannah agro-ecological zone along gender lines to identify resource constraints specific to gender that prevent smallholder farmers from adopting CSA practices. In doing so, we sought to answer two important questions; first, what factors influence the joint adoption of CSA practices based on their resource requirements?, and second, what factors influence the extent of adoption within each resource-based typology of CSA practices?

The rest of the paper is organized as follows: section two contains the methods used for the study; and section three presents the results while section four discusses the results of the study. The study's conclusions and policy implications are presented in section five.

Methods

Study area and sampling procedure

Three districts in Northern Ghana were chosen for the study: West Mamprusi Municipality in the North East Region, Bongo District and Bolgatanga Municipality in the Upper East Region (Fig. 1). These districts are located in the Sudan Savannah agro-ecological zone, which has a unimodal rainfall pattern that occurs from May/June to September/October every year. The North East and Upper East Regions were specifically chosen due to their heightened susceptibility to climatic events like floods, droughts, and variations in the mean temperature. The three local assemblies were selected because of their vulnerability to climate change and high dependence on rain-fed agriculture [26, 27].

Ultimately, the study respondents came from seven communities that raised livestock and farmed crops, as recommended by district agricultural extension officers. These communities were Ayelbia, Sinabisi, and Feo-Asabere from the Bongo District; Sagadugu and Minima from the West Mamprusi Municipality, and Yikene and Zaare from the Bolgatanga Municipality. A total of 350 smallholder farmers from these 7 study communities were surveyed for the study. The required sample size for the three districts was based on size proportion [28].

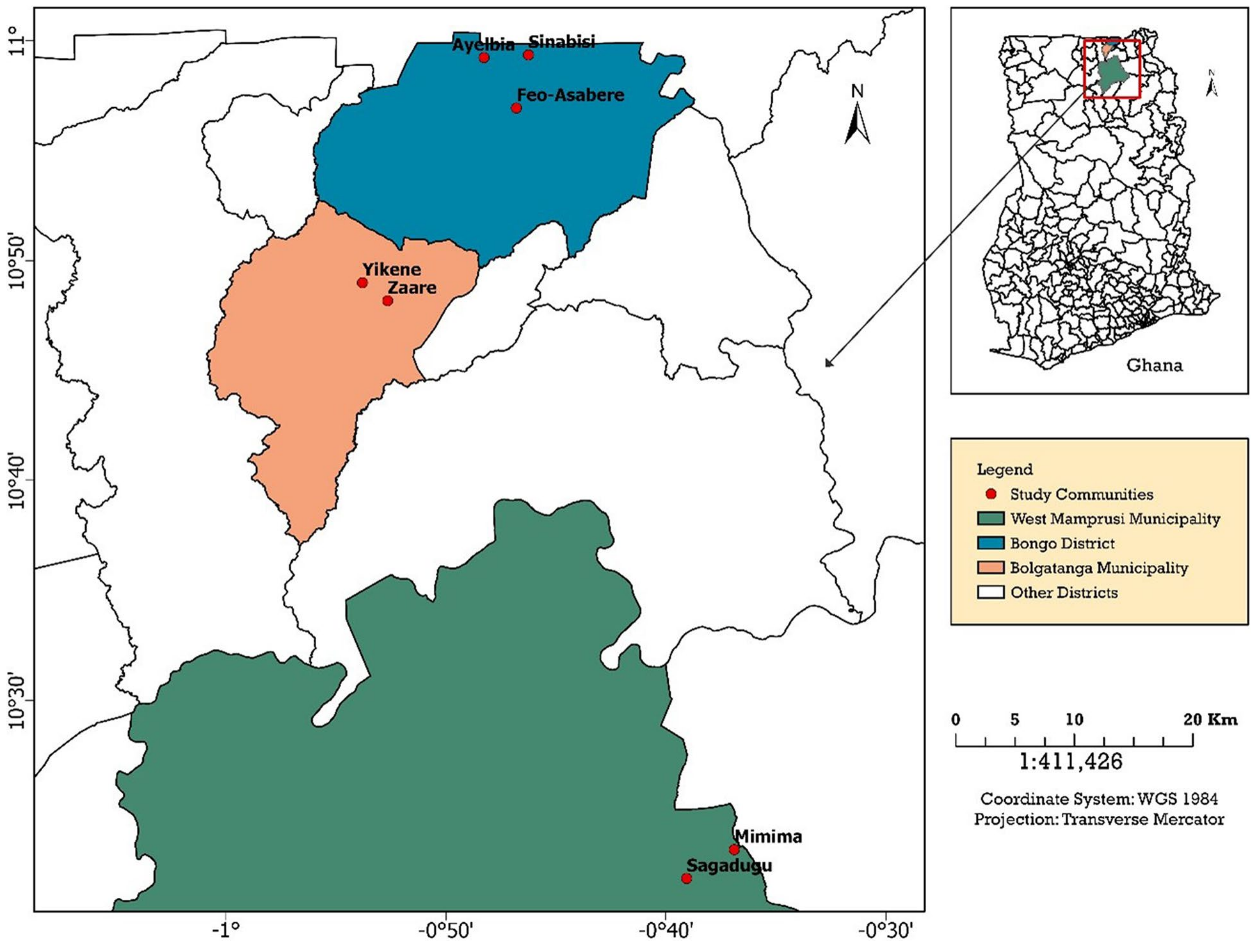

Fig. 1 Location of study areas

With a combined population of about 450,000, the sample size determination table proposed by [28] suggested a sample size of about 384, however, we achieved data saturation with the 350th farmer. This was because we observed that additional data no longer provided new insights as responses begun to become repetitive and that going beyond 350 farmers would not add any significant value to the study.

Data collection

A cursory look at the literature on CSA adoption particularly among smallholder farmers in Ghana revealed that farmers' adoption of CSA practices being promoted by government agencies was dependent on the availability of resources required for the full adoption of such practices [11]. It was observed that different CSA practices required different levels of resources for their full and successful implementation. Some categories of CSA practices required farmers to expand their current farm sizes, i.e., CSA practices that required more land. Other CSA practices required farmers to have access to additional farm labour for successful implementation while others required farmers to have additional financial resources to enjoy their full complements. With this in mind, further interviews were carried out using a detailed structured questionnaire. The questionnaire contained questions on the socio-demographic characteristics of farmers, farm characteristics, institutional factors, the experience of climatic shocks, behavioural measures and the adoption of several CSA practices. The questionnaire was developed for a larger project and has been published along with the study [21]. On average, each interview lasted about 50 min. The questionnaires were administered using the CSPro software. The survey was conducted between August and September of 2021 using locally trained enumerators. The interviews were conducted in the Gurne and Mumprusi dialects which are the local language in these study communities. The responses were however translated and recorded in the English language. To ensure validity and reliability of the questionnaire used, a draft of the questionnaire was pre-tested on some farmers around the Kwame Nkrumah University of Science and Technology community to identify issues relating to inconsistent and unclear questions. Issues raised during the pre-test were used to revise the questionnaire to increase its validity and reliability. Additionally, the drafted questionnaire was circulated to experts of different backgrounds who contributed to the study [21] and rated the questionnaire fit for data collection.

Typology of CSA practices in the study area

Twelve CSA practices used by farmers in the study communities were categorised under three main resource requirement categories (Table 1). These are; (1) land use i.e., CSA practices that require the use of more land for successful implementation; (2) labour i.e., CSA practices that are labour-intensive and require the farmer to engage more labour to adequately implement and; (3) finance i.e., CSA practices that are finance-intensive and would require the farmer to seek extra funds to fully adopt and implement on his/her farm. We acknowledge that our study faces the limitation of distinctively assigning each CSA practice into a category because of the likelihood of multiple requirements, we address this challenge by assigning each CSA practice to the most essential resource without which the adoption of that practice is impossible.

Table 1 Categorisation of CSA practices based on main resource requirement

S/N	CSA practices	Resource requirements			References
		Land	Labour	Finance	
1	Water harvesting	✓			[29]
2	Drip irrigation			✓	[30]
3	Cover cropping		✓		[31, 32]
4	Earth bunding		✓		[33]
5	Zero/minimum tillage	✓			[12, 34, 35]
6	Tillage by bullock			✓	[36]
7	Composting		✓		[37]
8	Crop rotation	✓			[38]
9	Crop-livestock integration			✓	[39, 40]
10	Agroforestry	✓			[12, 41, 42]
11	No burning of crop residues		✓		[43]
12	Drought-tolerant crop varieties			✓	[44, 45]

Source: Authors' construction

Theoretical framework and estimation techniques

Theoretical framework

The random utility theory forms the basis of our conceptualisation of farmers' decision to adopt CSA practices. Based on the assumptions of this theory, a farmer will adopt a CSA practice if the utility of adoption (U^A) surpasses the utility of non-adoption (U^N). Although the utility of adoption is unobservable, the adoption decision (A^*) can be observed and this is expressed as a binary variable in Eq. (1)

$$A^* = 1 \text{ if } U^A > U^N > 0; \text{ and } A^* = 0 \text{ if } U^N > U^A > 0 \quad (1)$$

A CSA adopter in this case is any farmer who implements at least one CSA practice from any of the CSA typologies on their farms yearly. From Eq. (1), the adoption decision of a farmer is expressed as a latent variable in Eq. 2:

$$A_f^* = \beta Z_f + \varsigma_i, \text{ for } A = 1 \text{ if } A_f^* > 0 \quad (2)$$

where A_f^* represents CSA adoption. Z_f represents a vector of the factors influencing CSA adoption, β represents a vector of coefficients to be predicted and ς_j is a normally distributed error term.

It is acknowledged that farmers adopt a mix of CSA practices to address the numerous production constraints they face and as such, their adoption decision is inherently multivariate. To overcome this challenge, we adopted the multivariate probit model which allows for the simultaneous modelling of a set of independent variables on each CSA practice adopted. Any effort to model such adoption in a univariate manner will eliminate relevant economic data about interdependent and concurrent adoption decisions [46]. The econometric specification for this study comes in two parts: (1), farmers' choice of interrelated resource-based CSA typologies was modelled using a multivariate probit (MVP); (2) a multivariate ordered probit (MVOP) model was used to assess the factors that influence the intensity of combinations of interrelated resource-based CSA typologies.

Multivariate probit model

A multivariate probit model was employed to analyse the factors that influenced farmers' decision to adopt different typologies of CSA practices. The MVP was deemed appropriate because farmers could adopt multiple CSA categories since the choice of CSA practices was not mutually exclusive (i.e., a farmer can simultaneously choose multiple CSA practices belonging to different resource-based categories) [19]. This model was preferred to other econometric models because of its robustness in establishing the correlation between unobserved disturbances, which may arise from the complementarities and substitutabilities between the different typologies of CSA practices [47].

Given a set of categories of CSA practices, say, (j = K, L, F), CSA practices that fall under K are land-intensive, L are labour-intensive while F are finance-intensive. With this, a farmer is faced with the decision on the mix of categories to adopt. Adopting the j^{th} category of CSA practices is hypothesised to be determined by farmer and farm characteristics, as well as climate shocks and institutional factors.

Following [25] the selection of a category of CSA practices j by farmer k is defined as y_{jk}. The choice of farmer k to adopt category j ($y_{jk}=1$) or not ($y_{jk}=0$) is given by:

$$y_{jk} = \begin{cases} 1 \; if \; y_{jk} = x'_{jk}\beta + \varepsilon_{jk} \geq 0, x'_{jk}\beta \geq -\varepsilon_{jk} \\ 0 \; if \; y_{jk} = x'_{jk}\beta + \varepsilon_{jk} < 0, x'_{jk}\beta < -\varepsilon_{jk} \end{cases} \quad (3)$$

where β represent parameter estimates and ε_{jk} represents the error terms which are normally distributed, y_{jk} is the dependent variable representing $land-intensive\ CSA\ practices_k$, $labour-intensive\ CSA\ practices_k$, and $finance-intensive\ CSA\ practices_k$ which are dichotomous variables that assume a value of 1 when farmer k chooses CSA practices that are land-intensive, labour-intensive and finance-intensive respectively. x'_{ij} is the combined effect of the explanatory variables.

The MVP produces a set of error terms which jointly follow a multivariate normal distribution (MVN) characterised as (ε_K, ε_L, ε_F) ≈ MVN (0, Ω). Additionally, the MVP provides a symmetric covariance matrix Ω (*nxn* correlation matrix) which is defined as:

$$\Omega = \begin{bmatrix} 1 & \rho KL & \rho KF \\ . & 1 & \rho LF \\ . & . & 1 \end{bmatrix} \quad (4)$$

The non-zero off-diagonal elements in the covariance matrix represent the unobserved correlation between the stochastic components of the different CSA typologies. Positive and negative correlation coefficients from the resulting correlation coefficients indicate the complementarity and substitutability associations among the various typologies of CSA.

Multivariate ordered probit model

From the theoretical framework and the MVP model specified in Eq. (3), it is conceptualised that a farmer's decision to adopt one or more practices within any typology of CSA is premised on the farmer's comparison of the net benefit of adopting and not adopting new practices within a given typology. A farmer will only choose to adopt additional practices within a given CSA typology if the benefit outweighs the benefit of not adopting. Farmers will tend to adopt more practices within a given CSA typology if greater benefits were derived from previously adopting a practice within that typology. However, the MVP model is incapable of capturing the extent of adoption within the various typology of CSA practices, additionally, the univariate ordered probit model which is used to estimate adoption intensity becomes obsolete in our case since we are dealing with ordered categorical and interrelated dependent variables.

The MVOP model is an extension of the univariate ordered probit model [48]. In this modelling framework, we assume the presence of an underlying set of multivariate continuous latent variables whose horizontal partitioning maps into an observed set of ordered outcomes (in this study, that is the intensity of adoption of CSA practices within each resource-based typology) [48]. Such a system of ordered response permits the use of a general covariance matrix for the underlying latent variables, which then translates into a flexible correlation pattern between the observed outcomes. We adopted the composite marginal likelihood approach to estimate our multivariate ordered response model because this approach produces consistent and unbiased estimates using a simple estimation technique and requires no simulation machinery [49].

By way of formulation, let g represent an index for farmers (g = 1, 2, ..., G), and let i represent the index for CSA category variables (i = 1, 2, 3). Let the number of response values for CSA category variable i be K_i. In the typically ordered response framework notation, the latent propensity (y^*_{gi}) for each CSA category is given as a function of the relevant covariates and related to the observed ordered outcome (y_{gi}) through threshold bounds [50]:

$$y^*_{gi} = \beta'_i x_{gi} + \varepsilon_{gi},\ y_{gi} = k \qquad if\ \theta_i^{k-1} < y^*_{gi} < \theta_i^k \quad (5)$$

where, x_{gi} is an (L X 1) vector of exogenous variables (without a constant), $\beta_i\prime$ is a corresponding (L X 1) vector of estimated coefficients, ε_{gi} is a standard normal error term and θ_i^k is the upper bound threshold for the ordered response level k of CSA category i ($\theta_i^0 < \theta_i^1 < \theta_i^2 < \cdots < \theta_i^{K_i}; \theta_i^0 = -\infty, \theta_i^{K_i} = +\infty$ for each category of i).

The threshold bounds describe a range of the underlying latent continuous variable that matches each observed discrete outcome. We assume all the error terms are independent and identical for each and all i. The variance of each error term was normalised to one for identification purposes, however, the model allows the error terms to correlate across CSA categories i for each farmer g. If $\varepsilon_g = (\varepsilon_{g1}, \varepsilon_{g2} \ldots \varepsilon_{gI})\prime$, then ε_g

is multivariate normally distributed (N) with a mean of zeros and a correlation matrix Σ as presented below:

$$\varepsilon_g \sim N[0, \Sigma] \tag{6}$$

The off-diagonal terms Σ capture the effects of common unobserved factors that impact the propensity of ordered response levels for each CSA category. The parameter vector of the multivariate ordered probit model is given as

$$\delta = (\beta_1', \dots \beta_I'; \theta_1' \dots \theta_I'; \Omega')' \tag{7}$$

Let m_{gi} represent the actual observed ordered response level for farmer g and CSA category i. The ensuing likelihood function (L) for farmer g will be written as:

$$L_g(\delta) = \Pr(y_{g1} = m_{g1}, \dots y_{gI} = m_{gI}) \tag{8}$$

In other words

$$Lg(\delta) = \int_{v_1=\theta_1^{m_{g1}-1}-\beta_1' x_{g1}}^{\theta_1^{m_{g1}}-\beta_1' x_{g1}} \dots \int_{v_I=\theta_I^{m_{gI}-1}-\beta_I' x_{gI}}^{\theta_I^{m_{gI}}-\beta_I' x_{gI}} \phi_I(v_1, \dots, v_I|\Omega) dv_1, \dots dv_I \tag{9}$$

Where Pr is probability and ϕ_I is a probability density function of an I-dimension multivariate normal distribution. The likelihood function stated in Eq. (9) necessitates the computation of an I-dimensional rectangular integral which may pose problems for a large sample size of 350. To overcome this challenge, we employed the pairwise marginal likelihood estimation approach which corresponds to a composite marginal approach based on bivariate margins [49]. The pairwise marginal likelihood function (L) for farmer g was then written as:

$$L_{CML,g}(\delta) = \prod_{i=1}^{I-1} \cdot \prod_{h=i+1}^{I} \Pr(y_{gi} = m_{gi}, y_{gh} = m_{gh}) \tag{10}$$

Where CML is the composite marginal likelihood. The pairwise likelihood function as given is easily maximised with the same effort as the usual bivariate ordered probit model. The pairwise estimator obtained by maximising the logarithm of Eq. (10) with respect to the vector δ is consistent and asymptotically normally distributed. The definitions of the various variables used in the estimation of the models are presented in Table 2.

Results

Descriptive results

Table 3 presents the descriptive statistics of the variables used in this study disaggregated by the sex of the farmer and the adoption status within each of the three CSA typologies. Column (5) presents the mean differences between the male and female samples. Columns (8), (11) and (14) present the mean differences between the characteristics of adopters and non-adopters of land-intensive, labour-intensive and finance-intensive respectively. The results of the t-test revealed no significant gender differences in the adoption rate of the different CSA typologies. However, Fig. 2 shows that the adoption of finance-intensive CSA practices was relatively higher among male famers than female farmers. Male farmers were significantly more educated and with a significantly higher proportion having more assets (proxied by ownership of television sets) than their female counterparts. Male farmers also had significantly larger farm sizes and had more access to extension services than female farmers. This conforms to that of [52] who also indicated that male farmers tend to have more extension contact than their female counterparts. Significantly more female farmers had access to credit and are significantly older than their male counterparts. We find significantly more females having membership of farmer-based groups than male farmers. We also find that adopters within each of the three CSA typologies have significantly more access to the input market and extension services than the non-adopters.

We further interrogate the adoption rates within each CSA resource-based typology graphically to present a visual understanding of the rate of adoption (Fig. 2). We find that adoption was highest among the labour-intensive CSA practices. We find that about 80% of farmers adopted at least one labour-intensive CSA practice on their farms. Adoption of land-intensive CSA practices was also high with about 73% of farmers reporting to have adopted at least one land-intensive CSA practice on their farms. Adoption was lowest in the finance-intensive CSA practices where about 55% of farmers indicated that they adopted at least one finance-intensive CSA practice. While the adoption of at least one CSA practice seem to show an appreciable level of adoption, an examination of the extent of adoption reveals a different trend. The extent of adoption was highest within the labour-intensive CSA typology where about 23% of farmers indicated that they adopted all four labour-intensive CSA practices compared to about 3% and less than 1% of farmers for land-intensive and finance-intensive CSA typologies respectively. This implies that farmers in the study communities adopted CSA practices that required more labour but were adamant to adopt finance-intensive and land-intensive CSA practices.

Multivariate probit model results: adoption of CSA typologies

Table 4 shows the error correlation matrix of the multivariate probit model of farmers based on their choice of CSA practices concerning resource requirement.

Table 2 Definition of variables and measurement

Variable	Description and measurement	Unit of measurement
Outcome/dependent variables		
Binary measure of adoption [used in the MVP model]		
Land intensive	Adoption of at least one land-intensive CSA on a farm = 1 if yes; 0 otherwise	Dummy
Labour intensive	Adoption of at least one labour-intensive CSA on farm = 1 if yes; 0 otherwise	Dummy
Finance intensive	Adoption of at least one finance-intensive CSA on the farm = 1 if yes; 0 otherwise	Dummy
Ordinal measure of adoption [counts the number of CSA practices within a resource-based typology adopted by a farmer – used in the MVOP]		
Land intensive (intensity)	Number of land-intensive CSAs adopted simultaneously by farmer; ranges from 0 to 4	Ordinal
Labour intensive (intensity)	Number of labour-intensive CSAs adopted simultaneously by farmer; ranges from 0 to 4	Ordinal
Finance intensive (intensity)	Number of finance-intensive CSAs adopted simultaneously by farmer; ranges from 0 to 4	Ordinal
Household characteristics		
Sex	Sex of the farmer = 1 if farmer is female; 0 otherwise	Dummy
Household size	Number of people in the household including the farmer	Continuous
Age	Age of the farmer in years	Continuous
Education level	Level of education of the farmer = 0 if none; 1 if primary; 2 if secondary and above	Categorical
Marital status	Marital status of the farmer = 0 if unmarried; 1 if married; 2 if widowed	Categorical
Source of income	Main income source of farmer = 1 if on-farm income; 0 if off-farm income	Dummy
Owns a TV	Ownership of television by the farmer = 1 if owns a television; 0 otherwise	Dummy
Farm characteristics		
Farm size	Total combined farm size under cultivation in acres	Continuous
House-to-farm distance	Total distance from the home of a farmer to his/her farm in kilometres	Continuous
Farming experience	Number of years engaged as a farmer	Continuous
Institutional factors		
Land tenure security	Farmer's perceived security of land tenure rights = 1 if secured; 0 otherwise	Dummy
Access to credit	Does the farmer have access to credit for farm operations = 1 if yes; 0 otherwise	Dummy
Access to input market	Does the farmer have ready access to farm input market = 1 if yes; 0 otherwise	Dummy
Access to extension	Did the farmer have access to extension services in past year = 1 if yes; 0 otherwise	Dummy
Member of FBO	Does the farmer belong to any farmer-based organization = 1 if yes; 0 otherwise	Dummy
Behavioural factors[a]		
Subjective norms	The extent of perceived social influence on farmers adoption decision	Continuous
Perceived behaviour control	The extent of perceived easiness or difficulty in implementing CSA on farmland	Continuous
Climate shocks		
Experienced flood	Has the farmer ever experienced flooding on farm = 1 if yes; 0 otherwise	Dummy
Experience drought	Has the farmer ever experienced drought on farm = 1 if yes; 0 otherwise	Dummy
Location fixed effects	District of resident of the farmer = 0 if Bongo; 1 if Mamprusi; 2 if Bolgatanga	Categorical

[a] Behavioural factors were derived based on the theory of planned behaviour [51] which argues that economic incentives are not the sole motivation for the actions (adoption of CSA in this case) of individuals (i.e., farmers) but that socio-psychological factors also influence the actions of individuals. The two variables included in this study measures the role of such socio-psychological factors. Specifically, subjective norm measures the perceived social influence from internal and/or external sources while perceived behaviour control measures the perceived easiness or difficulty in carrying out a behaviour

Table 3 Summary statistics of variables

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Pooled sample		Gender decomposition			Land-intensive CSA			Labour-intensive CSA			Finance-intensive CSA		
	Mean	Std dev	Male	Female	Mean diff	Non adopter	Adopter	Mean diff	Non adopter	Adopter	Mean diff	Non adopter	Adopter	Mean diff
Outcome variables														
Land intensive	0.729	0.445	0.737	0.722	0.015									
Labour intensive	0.806	0.396	0.802	0.808	−0.005									
Finance intensive	0.549	0.498	0.586	0.520	0.066									
Land intensive (intensity)	1.394	1.102	1.408	1.384	0.024									
Labour intensive (intensity)	2.071	1.438	1.967	2.151	−0.184									
Finance intensive (intensity)	1.026	1.098	1.086	0.980	0.105									
Household characteristics														
Sex	0.566	0.496				0.579	0.561	0.018	0.559	0.568	−0.009	0.602	0.536	0.065
Household size	7.824	3.075	7.877	7.784	0.092	7.821	7.825	−0.005	7.942	7.796	0.146	8.598	7.187	1.411***
Age	39.523	12.099	37.368	41.177	−3.808***	40.663	39.098	1.565	40.397	39.312	1.085	39.627	39.438	0.189
Education level	0.64	0.711	0.875	0.460	0.416***	0.558	0.670	−0.113	0.662	0.635	0.027	0.645	0.636	0.010
Marital status	1.737	0.576	1.763	1.717	0.046	1.748	1.734	0.014	1.691	1.748	−0.057	1.804	1.683	.121**
Source of income	0.183	0.387	0.158	0.202	−0.044	0.242	0.161	0.082	0.220	0.174	0.047	0.190	0.177	0.013
Owns a TV	0.351	0.478	0.461	0.268	0.193***	0.379	0.341	0.038	0.324	0.358	−0.035	0.380	0.328	0.052
Farm characteristics														
Farm size	2.276	2.481	2.921	1.782	1.139***	1.919	2.409	−0.49*	2.493	2.224	0.269	2.224	2.32	−0.097
House-to-farm distance	14.136	44.214	10.822	16.68	−5.858	6.184	17.098	−10.914***	5.950	16.11	−10.159***	5.383	21.339	−15.957***
Farming experience	16.08	12.005	16.369	15.859	0.510	18.274	15.263	3.011*	17.897	15.642	2.255	17.943	14.547	3.396***
Institutional factors														
Land tenure security	0.363	0.482	0.382	0.349	0.033	0.390	0.353	0.036	0.280	0.383	−0.104*	0.475	0.271	0.204***
Access to credit	0.200	0.401	0.138	0.247	−0.110***	0.200	0.200	0.00	0.236	0.192	0.044	0.247	0.162	0.086*
Access to input market	0.723	0.448	0.724	0.722	0.002	0.611	0.765	−0.154***	0.721	0.724	−0.003	0.633	0.797	−0.164***
Access to extension	0.463	0.499	0.519	0.419	0.101*	0.263	0.537	−0.274***	0.353	0.489	−0.137**	0.253	0.636	−0.383***
Member of FBO	0.500	0.501	0.427	0.555	−0.128**	0.494	0.502	−0.007	0.544	0.489	0.055	0.531	0.474	0.058
Behavioural factors														
Subjective norms	0.000	1.001	−0.025	0.019	−0.044	0.296	−0.110	0.406***	0.284	−0.069	0.352**	0.225	−0.185	0.411***
Perceived behavior control	−0.076	0.834	0.013	−0.145	0.159	−0.266	−0.006	−0.26**	−0.098	−0.072	−0.026	−0.194	0.020	−0.214**
Climate shocks														
Experienced flood	0.617	0.487	0.592	0.637	−0.044	0.663	0.600	0.063	0.633	0.614	0.019	0.583	0.646	−0.064
Experience drought	0.434	0.496	0.441	0.429	0.011	0.337	0.471	−0.134**	0.265	0.475	−0.21***	0.361	0.495	−0.134**

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Fig. 2 Adoption percentages within the various CSA typologies

The positive correlation coefficient between the error terms of the set of CSA typologies suggests that farmers use them to complement one another but not as substitutes. We found a positive relationship between each pair of CSA typology indicating that farmers use a mix of labour-intensive, land-intensive and finance-intensive CSA practices on their farmlands. This implies that the mix of these CSA practices may depend on the resource that is most available to the farmer.

Table 5 presents the result of the MVP model (Eq. 3). The Log-likelihood values of −435.177, −156.627 and −225.595, and the Wald chi-square value of 202.530 ($p < 0.01$), 168.100 ($p < 0.01$) and 172.040 ($p < 0.01$) for the pooled, male and female regressions respectively indicate good model fit, implying that the independent variables significantly explain the predicted variables.

Land-intensive CSA practices

Columns (1), (2) and (3) of Table 5 present the factors that influence farmers' adoption of land-intensive CSA practices based on the pooled, male and female samples, respectively. We find that farmers with primary education were about 42% more willing to adopt land-intensive CSA practices than uneducated farmers. The marital status of farmers plays a significant role in their adoption of land-intensive CSA practices. Married farmers were about 58% more likely, while widowed farmers were about 92% less likely to adopt land-intensive CSA practices compared to unmarried farmers.

We further observe that farmers whose main source of income is from on-farm activities are about 49% more likely to adopt land-intensive CSA practices compared to farmers whose main income source is from off-farm activities. Our results show that farmers who have access to input market and extension services are about 80% and 81% more likely to adopt land-intensive CSA practices respectively. Gender-wise, men farmers with access to input market and extension services are about 96% and 95% likely to adopt land-intensive CSA practices compared to the likelihood of 90% and 72% among women farmers.

We find that farmers who have experienced drought in the past are about 52% more likely to adopt land-intensive CSAs and this is particularly the case among female farmers. Finally, we observe that farmers who perceive easiness in the adoption of CSAs are about 20% more likely to adopt land-intensive CSA practices. This is particularly common among female farmers than male farmers.

Table 4 Correlation matrix of error terms after MVP model estimation

	Land-intensive	Labour-intensive	Finance-intensive
Land-intensive	1	0.693***	0.694***
Labour-intensive		1	0.695***
Finance-intensive			1

Table 5 Determinants of CSA adoption based on resource requirements

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Land intensive CSA			Labour intensive CSA			Finance intensive CSA		
	Pooled	Male	Female	Pooled	Male	Female	Pooled	Male	Female
Household and farm characteristics									
Sex	0.201			−0.007			−0.364**		
	(0.182)			(0.177)			(0.170)		
Household size	0.030	0.032	0.034	−0.012	−0.032	−0.018	−0.061**	−0.117***	−0.038
	(0.026)	(0.044)	(0.040)	(0.027)	(0.045)	(0.049)	(0.027)	(0.043)	(0.040)
Age	0.007	−0.0234	0.035	−0.020	0.096	0.036	0.004	−0.016	0.019
	(0.032)	(0.083)	(0.048)	(0.171)	(0.741)	(0.235)	(0.033)	(0.081)	(0.050)
Age squared	−0.022	0.123	−0.188	0.131	−0.176	−0.008	−0.000	0.000	−0.000
	(0.648)	(1.679)	(0.982)	(0.211)	(0.141)	(0.284)	(0.000)	(0.001)	(0.001)
Education level (Base = no education)									
Primary school	0.423**	0.006	0.751*	0.484*	−0.000	1.178***	0.491**	0.385	0.760*
	(0.192)	(0.397)	(0.439)	(0.267)	(0.394)	(0.443)	(0.225)	(0.372)	(0.411)
Secondary school and above	0.115	−0.425	0.158	0.333	−0.006	0.112***	0.666***	0.649	0.755*
	(0.270)	(0.399)	(0.469)	(0.277)	(0.377)	(0.044)	(0.247)	(0.406)	(0.454)
Marital status (Base = unmarried)									
Married	0.580*	0.845	0.590*	0.331	−0.552	0.800**	−0.185	−0.813	0.069
	(0.345)	(0.890)	(0.310)	(0.263)	(0.998)	(0.377)	(0.272)	(1.631)	(0.301)
Widowed	−0.918**	1.096	−0.334***	0.746	0.061	−0.034	0.117	−0.904	0.313
	(0.441)	(1.046)	(0.061)	(0.523)	(1.129)	(0.612)	(0.385)	(1.653)	(0.493)
Source of income	0.486**	0.769*	0.668**	0.449**	−0.061	0.796**	0.322	0.450	0.234
	(0.226)	(0.427)	(0.300)	(0.227)	(0.529)	(0.332)	(0.223)	(0.429)	(0.293)
Owns a television	0.214	0.217	0.128	0.265	0.322	0.034	0.021	−0.415	0.295
	(0.179)	(0.311)	(0.251)	(0.214)	(0.326)	(0.331)	(0.174)	(0.306)	(0.264)
Farm size	−0.010	0.137	−0.173	−0.178*	−0.253	−0.069	0.037	0.049	0.040
	(0.097)	(0.189)	(0.135)	(0.101)	(0.209)	(0.161)	(0.028)	(0.054)	(0.054)
House-to-farm distance	0.002	0.016	0.002	0.126**	0.207	0.108	0.004*	0.021	0.003
	(0.003)	(0.016)	(0.003)	(0.055)	(0.145)	(0.092)	(0.002)	(0.019)	(0.003)
Farming experience	−0.003	0.007	−0.010	−0.009	−0.031*	0.003	−0.006	−0.011	−0.001
	(0.009)	(0.017)	(0.011)	(0.009)	(0.018)	(0.013)	(0.009)	(0.018)	(0.012)
Institutional factors									
Land tenure security	0.095	0.367	0.141	0.389*	0.728	0.337	−0.083	−0.305	−0.261
	(0.213)	(0.408)	(0.286)	(0.230)	(0.444)	(0.345)	(0.201)	(0.406)	(0.319)
Access to credit	0.110	0.181	−0.026	0.006	−0.082	−0.087	−0.003	0.342	−0.268
	(0.228)	(0.464)	(0.288)	(0.213)	(0.431)	(0.305)	(0.208)	(0.429)	(0.260)
Access to input market	0.804***	0.958**	0.896***	0.284	0.702*	−0.265	0.573**	0.594	0.288
	(0.211)	(0.404)	(0.279)	(0.247)	(0.394)	(0.344)	(0.228)	(0.378)	(0.318)
Access to extension service	0.812***	0.945***	0.716***	0.149	0.063	0.395	0.805***	0.812**	0.994***
	(0.180)	(0.321)	(0.266)	(0.176)	(0.331)	(0.300)	(0.174)	(0.316)	(0.266)
Member of FBO	0.203	−0.418	0.397	0.122	−0.247	0.433*	0.125	−0.489	0.499**
	(0.183)	(0.335)	(0.286)	(0.177)	(0.366)	(0.254)	(0.181)	(0.339)	(0.247)
Behavioral factors									
Subjective norms	−0.109	−0.191	−0.088	−0.084	−0.228	−0.144	−0.180**	−0.373***	−0.166
	(0.089)	(0.142)	(0.129)	(0.087)	(0.162)	(0.128)	(0.079)	(0.143)	(0.110)
Perceived behavior control	0.199*	0.171	0.230*	0.046	−0.077	0.183	0.021	−0.280	0.149
	(0.106)	(0.200)	(0.133)	(0.094)	(0.209)	(0.139)	(0.100)	(0.193)	(0.127)

Table 5 (continued)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Land intensive CSA			Labour intensive CSA			Finance intensive CSA		
	Pooled	Male	Female	Pooled	Male	Female	Pooled	Male	Female
Climate shocks									
Experience flooding	−0.317	−0.526	−0.254	0.333*	0.020	0.692***	−0.040	−0.349	−0.514*
	(0.193)	(0.325)	(0.252)	(0.187)	(0.340)	(0.259)	(0.190)	(0.309)	(0.284)
Experienced drought	0.517***	0.476	0.533**	0.363**	0.692*	−0.065	0.669***	0.579*	0.984***
	(0.190)	(0.358)	(0.269)	(0.169)	(0.368)	(0.254)	(0.183)	(0.328)	(0.274)
District fixed effect (Base = Bongo)									
Mamprusi	0.331	0.392	0.207	−0.239	0.018	−0.205	0.410*	−0.390	0.376
	(0.263)	(0.452)	(0.335)	(0.245)	(0.485)	(0.418)	(0.243)	(0.476)	(0.356)
Bolgatanga	0.263	−0.392	0.037	0.074	−0.245	0.445	0.561**	−0.160	0.577
	(0.219)	(0.452)	(0.341)	(0.229)	(0.464)	(0.353)	(0.235)	(0.446)	(0.352)
Constant	−1.048	−2.088	−2.161	−1.760	−1.696	−2.398	−1.136	1.393	−2.292*
	(3.574)	(9.106)	(5.367)	(1.552)	(2.764)	(2.169)	(0.856)	(2.236)	(1.318)
Log likelihood							−435.177	−156.627	−225.595
Wald chi-square							202.530	168.100	172.040
Prob > chi-square							0.000	0.000	0.000
Observations							350	152	198
Likelihood ratio test of rho21 = rho31 = rho32 = 0: chi-square							119.719***		

Robust standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Labour-intensive CSA practices

Columns (4), (5) and (6) of Table 5 present the estimates for the factors that influence the adoption of labour-intensive CSA practices for the pooled, male and female samples respectively. We observe that farmers with a primary school level education are about 48% more likely to adopt labour-intensive CSA praxtices than uneducated farmers. Further, educated women are more likely to adopt labour-intensive CSA practices than their uneducated counterparts but this is not the case among male farmers. Married women and women who viewed agriculture as their main source of income were about 80% more likely to adopt labour-intensive CSA practices. Farmers with distant farms are estimated to be about 13% more likely to adopt labour-intensive CSA practices than farmers whose farms are closer to their place of residence. Farmers with larger farm sizes are however less likely to adopt labour-intensive CSA practices. Further, male farmers with more years of experience are about 3% less likely to adopt labour-intensive CSA practices.

In terms of institutional factors, we observe that farmers with secured land tenure are about 39% more likely to adopt labour-intensive CSA practices than farmers with less secured land tenure rights. Male farmers who have access to the input market are estimated to be 70% more likely to adopt labour-intensive CSA practices. Female farmers who belong to farmer-based organisations are about 43% more likely to adopt labour-intensive practices.

We observe that female farmers who have ever experienced flooding are about 69% more likely to adopt labour-intensive CSA practices than their counterparts who have never experienced flooding on their farms. The experience of flooding did not have any effect on the adoption of labour-intensive CSA practices among men farmers. On the contrary, male farmers who have experienced drought were about 69% more likely to adopt labour-intensive CSA practices than their counterparts with no such experience. Similarly, the experience of drought exhibited no significant effect on the likelihood of adoption among female farmers. We further observe no district-fixed effects in the adoption of labour-intensive CSA practices.

Finance-intensive CSA practices

Columns (7), (8) and (9) of Table 5 present the estimates for the factors that influence the adoption of finance-intensive CSA practices for the pooled, male and female samples respectively. We find that female farmers are about 36% less likely to adopt finance-intensive CSA practices compared to their male counterparts. We further observe that farmers with larger household sizes are about 6% less likely to adopt finance-intensive CSA practices with the impact being more entrenched in the male sample. Again, educated farmers are more likely to adopt finance-intensive CSA practices than uneducated farmers. The influence of education was more pronounced in the female sample than in the male sample. We find that female farmers who had primary education, and those who had attained secondary schooling and beyond were about 76% more likely to adopt finance-intensive CSA practices.

Access to input markets and extension services increases the likelihood of adopting finance-intensive CSA practices by about 57% and 81% respectively. Female farmers who had access to extension services had a greater likelihood of adoption than their male counterparts. Female farmers who belong to farmer-based organisations (FBOs) are about 50% more likely to adopt finance-intensive CSA practices than their counterparts who do not belong to any FBOs. We find that subjective norms, which measure the effect of social pressure on farmers' adoption behaviour reduce male farmers' likelihood of adopting finance-intensive CSA practices by about 37%.

Experiencing different forms of climate shock affects farmers' adoption of finance-intensive CSA practices in different ways. Female farmers who reported ever experiencing flooding on their farms are about 51% less likely to adopt finance-intensive CSA practices; however, such an experience has no significant effect on the likelihood of adoption among male farmers. The situation is however different from the experience of droughts. We find that farmers who reported ever experiencing drought were about 67% more likely to adopt finance-intensive CSA practices. The likelihood of adoption was proportionally higher among female farmers (98%) than among male farmers (58%). Lastly, we find that farmers in Mamprusi and Bolgatanga municipalities are more likely to adopt finance-intensive CSA practices than their counterparts in the Bongo district.

Multivariate ordered probit results: extent of adoption within CSA typologies

Table 6 presents the marginal effects[1] of the MVOP estimation of the extent of adoption within each CSA typology. The Log-likelihood value of −1199.05 and Wald chi-square value of 264.93 ($p < 0.01$) (see Table A1 in Appendices) is an indication of a good model fit and that our predictors significantly explain variations in the dependent variables.

Extent of adoption of land-intensive CSA practices

Columns (1), (2) and (3) of Table 6 present the marginal effects of the extent of adoption within the land-intensive CSA typology based on the pooled, male and female samples. Having at least a secondary school-level education, access to the input market and extension services, and being a member of a farmer-based organization increases the probability of adopting at least three land-intensive CSA practices among female farmers. Again, female farmers who have a stronger perception of their control over farm resources have a greater probability of adopting at least three land-intensive CSA practices. However, women in the Mamprusi enclave have a lower probability of adopting three land-intensive CSA practices. We find that having agriculture as the main source of income, secured land tenure rights, access to input market and extension services increases the probability of adopting at least three land-intensive CSA practices among male farmers. However, ever experiencing flooding has a negative effect on the probability of male farmers' adoption of at least three land-intensive CSA practices.

Extent of adoption of labour-intensive CSA practices

Columns (4), (5), and (6) present the marginal effects of the extent of adoption within the labour-intensive CSA typology based on the pooled, male and female samples. We observe that being educated, married and having agriculture as the main source of income increases the probability of female farmers adopting at least three labour-intensive CSA practices on their farms. Again, female farmers who have larger farm sizes, secured land tenure rights, access to extension services, belong to farmer-based organisations and have stronger perceived control over farm resources have a greater probability of adopting at least three labour-intensive CSA practices simultaneously on their farm. However, female farmers in Mamprusi have a lower probability of adopting at least three labour-intensive CSA practices. We further find that male farmers who have access to the input market and extension services have a greater probability of adopting at least three labour-intensive CSA practices. Conversely, exerting social pressure on male farmers has a negative effect on their probability of adopting labour-intensive CSA practices. Just as in the case of female farmers, male farmers from Mamprusi have a lower probability of adopting at least three labour-intensive CSA practices.

Extent of adoption of finance-intensive CSA practices

Columns (7), (8) and (9) present the marginal effects of the extent of adoption within the finance-intensive

[1] To make it simple and easy to follow the arguments of this study, we only present the marginal effect of the adoption of three CSA practices within a typology. The Stata commands and the estimates on the other marginal effects (i.e., combination of zero, one, two and four CSA practices) are available upon request.

Table 6 Determinants of the extent of CSA adoption within each resource requirement category

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Land intensive CSA			Labour intensive CSA			Finance intensive CSA		
	Pooled	Male	Female	Pooled	Pooled	Male	Female	Male	Pooled
Household and farm characteristics									
Sex	0.014 (0.018)			−0.024 (0.021)			−0.023 (0.020)		
Household size	0.001 (0.003)	0.001 (0.003)	0.004 (0.005)	0.000 (0.002)	0.000 (0.004)	0.002 (0.002)	−0.003 (0.003)	−0.008* (0.005)	0.002 (0.005)
Age	−0.001 (0.003)	−0.003 (0.005)	−0.006 (0.005)	0.006 (0.024)	−0.026 (0.055)	0.016 (0.020)	−0.000 (0.005)	−0.007 (0.008)	0.008 (0.007)
Age squared	0.025 (0.070)	0.018 (0.102)	0.146 (0.110)	−0.004 (0.009)	−0.007 (0.023)	−0.002 (0.008)	−0.000 (0.000)	0.000 (0.000)	−0.000 (0.000)
Education level (Base = no education)									
Primary school	−0.001 (0.028)	−0.052 (0.034)	0.050 (0.056)	0.026 (0.017)	0.015 (0.034)	0.031* (0.019)	0.086** (0.035)	0.090** (0.044)	0.064 (0.066)
Secondary school and above	0.030 (0.027)	−0.000 (0.030)	0.088* (0.054)	0.025 (0.016)	0.009 (0.031)	0.029* (0.018)	0.073** (0.032)	0.061 (0.039)	0.072 (0.062)
Marital status (Base = unmarried)									
Married	−0.002 (0.029)	0.058 (0.074)	0.022 (0.037)	0.018 (0.017)	−0.005 (0.074)	0.025* (0.013)	−0.028 (0.032)	−0.056 (0.092)	−0.010 (0.040)
Widowed	0.028 (0.044)	0.027 (0.083)	0.111 (0.072)	0.048* (0.027)	−0.007 (0.083)	0.041 (0.027)	−0.001 (0.050)	−0.065 (0.103)	−0.004 (0.076)
Source of income	0.050** (0.023)	0.085** (0.035)	0.042 (0.035)	0.037*** (0.014)	0.048 (0.034)	0.030** (o.012)	0.026 (0.026)	0.063 (0.042)	0.000 (0.038)
Owns a television	−0.001 (0.019)	0.019 (0.023)	−0.005 (0.032)	0.008 (0.011)	0.025 (0.025)	0.003 (0.010)	−0.005 (0.022)	−0.023 (0.029)	0.028 (0.035)
Farm size	0.011 (0.011)	0.011 (0.015)	0.006 (0.017)	−0.016** (0.006)	−0.012 (0.014)	0.015** (0.006)	0.004 (0.004)	0.004 (0.005)	0.002 (0.006)
House-to-farm distance	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	−0.000 (0.003)	0.004 (0.008)	−0.001 (0.003)	0.000* (0.000)	0.000 (0.000)	0.000 (0.000)
Farming experience	−0.001 (0.001)	0.000 (0.001)	−0.002 (0.001)	−0.000 (0.001)	−0.001 (0.001)	0.000 (0.000)	−0.001 (0.001)	−0.001 (0.002)	−0.000 (0.001)
Institutional factors									
Land tenure security	0.056** (0.023)	0.055* (0.032)	0.052 (0.035)	0.033** (0.014)	0.038 (0.032)	0.025** (0.012)	−0.040 (0.026)	−0.052 (0.038)	−0.044 (0.040)
Access to credit	0.006 (0.023)	0.048 (0.035)	−0.029 (0.033)	0.001 (0.013)	0.052 (0.036)	−0.010 (0.011)	−0.020 (0.026)	0.011 (0.044)	−0.030 (0.037)
Access to input market	0.109*** (0.025)	0.139*** (0.039)	0.090** (0.038)	0.034** (0.014)	0.117*** (0.037)	−0.002 (0.012)	0.090*** (0.028)	0.125*** (0.045)	0.078* (0.041)
Access to extension service	0.085*** (0.023)	0.069** (0.027)	0.101*** (0.034)	0.058*** (0.013)	0.064** (0.026)	0.050*** (0.014)	0.123*** (0.025)	0.105*** (0.034)	0.162*** (0.039)
Member of a FBO	0.030 (0.020)	−0.037 (0.028)	0.079** (0.022)	0.031** (0.012)	−0.036 (0.029)	0.047*** (0.014)	0.001 (0.022)	−0.040 (0.035)	0.053 (0.035)
Behavioral factors									
Subjective norms	−0.009 (0.009)	−0.014 (0.011)	−0.008 (0.015)	−0.007 (0.005)	−0.020* (0.011)	−0.005 (0.005)	−0.023** (0.010)	−0.032** (0.014)	−0.025 (0.016)
Perceived behavior control	0.025** (0.011)	0.016 (0.015)	0.036** (0.016)	0.009 (0.006)	−0.010 (0.015)	0.013** (0.006)	−0.003 (0.012)	−0.023 (0.019)	0.014 (0.018)
Climate shocks									
Experience flooding	−0.024 (0.021)	−0.047* (0.027)	−0.009 (0.030)	−0.002 (0.012)	−0.037 (0.027)	0.012 (0.010)	0.013 (0.022)	−0.046 (0.033)	0.066* (0.034)
Experienced drought	0.050*** (0.019)	0.035 (0.024)	0.050 (0.031)	0.012 (0.012)	0.018 (0.025)	0.003 (0.010)	0.068*** (0.022)	0.079** (0.031)	0.083** (0.036)
District fixed effect (Base = Bongo)									
Mamprusi	−0.062** (0.028)	−0.054 (0.039)	−0.087** (0.044)	−0.044*** (0.017)	−0.074* (0.041)	−0.027* (0.015)	−0.055* (0.032)	−0.064 (0.047)	−0.058 (0.049)
Bolgatanga	−0.032 (0.023)	−0.041 (0.035)	−0.042 (0.016)	0.003 (0.014)	−0.009 (0.035)	0.007 (0.011)	0.002 (0.026)	0.002 (0.043)	0.008 (0.037)

Standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

CSA typology based on the pooled, male and female samples. We find that larger household sizes and increasing social pressure have a negative effect on the probability of adopting at least three finance-intensive CSA practices among male farmers. We also find that having at least a primary level education, access to the input market, access to extension services and ever-experiencing drought increases the probability of adopting at least three finance-intensive CSA practices among male farmers. It is expected that farmers realizing the effect of drought on their farming activities will be more willing to invest in technologies that can help them maximise their farm output. Further, we observe that access to input markets and extension services as well as ever experiencing any climate shock (i.e., flooding or drought) increases the probability of adopting at least three finance-intensive CSA practices among female farmers. In general, the farther a farmers' house is from the farm, the greater the probability of adopting at least three finance-intensive CSA practices.

Discussion

The empirical results of our study show that the adoption of CSA practices by farmers depend on the kinds of resources needed to fully adopt and implement such practices. We find that labour-intensive CSA practices were the most adopted followed by land-intensive CSA practices. Just about half of smallholder farmers adopted CSA practices that are finance-intensive. We found gender to play no role in the adoption of both land-intensive and labour-intensive CSA practices despite the assertion that women in sub-Saharan Africa have limited control over land and tend to spend much of their labour on household duties [16]. This finding suggests that the limited access to land by women in no way hinder their adoption of land-intensive CSA practices. Additionally, women, despite being overburdened by domestic chores find time to provide the needed labour necessary for the successful adoption of certain types of CSA practices. However, women were observed to be less likely to adopt finance-intensive CSA practices which is testament to the fact that women have less control over the financial resources. Additionally, the district fixed effect variable showed differences in adoption rates and indication of the differences in resource availability among farmers within these districts.

Our results further revealed that the marital status positively influenced the adoption of land-intensive CSA practices. We argue that marriage serves as a means to access a larger pool of land resources in the sub-Saharan region given that the majority of lands tend to be held by families. As a result, married couples can access farmlands from both the families of the male and female making them relatively less constrained in terms of land resources as compared to unmarried farmers [53]. However, upon the demise of a spouse, families tend to repossess lands that were given out to the deceased hence reducing the availability of land to the surviving partner. Our results also indicated that farmers who saw agriculture as their main source of income were more likely to adopt land-intensive CSA practices. This goes to say that farmers with alternative income sources may be less concerned about expanding their farmlands given that they may just be engaged in the farm for subsistence.

Further, we found access to extension services to be a key determinant of land-intensive CSA practices. Extension access equips farmers with the requisite knowledge and skills, thereby reducing farmers' risk aversion. Farmers with extension access are most probable to expand their farms to accommodate land-intensive practices with their knowledge that their toil may not go to waste due to climate change [54, 55]. Additionally, land-intensive CSA practices imply increased farmlands and this may require additional farm inputs [56]. As such farmers who have easy access to farm input will be more likely to adopt such land-intensive CSA practices. Access to extension also has implication on the number of land-intensive CSA practices that a farmer may adopt. Access to extension services tend to expose farmers to the need to combine various CSA practices to maximise their synergistic effect on their production [20]. This ultimately may enhance the adoption of multiple land-intensive practices.

Although the role of behavioural factors such as perceived behaviour control was found to enhance the adoption of land-intensive CSA practices, their role in the adoption of land-intensive CSA practices such as agroforestry has been disputed by [57]. The authors argued that such behavioural factors may affect farmers intentions but not their actual adoption behaviour indicating an intention-behaviour gap in the adoption process. While farmer's experience of drought may enhance their adoption of land-intensive CSA practices, the effect of experiencing flooding reduced the adoption of multiple land-intensive practices. This could be because more land-intensive CSA practices would require larger farmlands which also increases the likelihood of getting your farm flooded and losing one's investment, particularly in a flood-prone area like the study districts [58]. Adopting more land-intensive CSA practices invariably means expanding one's farm size, however, increasing one's farm size also increases the risk of flooding given that the farmer now has a wider land space.

Our study further highlights the factors that influenced farmers' adoption of labour-intensive CSA practices. We found that married female farmers are more likely to adopt labour-intensive CSA practices. We argue that married women may tend to have a larger household size compared to unmarried women hence their greater likelihood of adopting practices that may require more labour. This is because they know that they can fall on their household members to meet the labour demands of such practices. This is consistent with existing arguments that claim that farmers with larger household sizes may opt for labour-intensive practices which may come at a lower cost since they are likely to use household labour [50, 59]. Farmers with an already large farm size were found to be less likely to adopt labour-intensive CSA practices. This is because large farms already require more labour and as such adopting labour-intensive practices may require an increase in labour demand which will add up to the labour cost of the farmer.

Our results also show that male farmers with more years of farming experience were less likely to adopt labour-intensive CSA practices. This is because farmers with extensive experience know of the resources required to carry out each practice and therefore, they may be unwilling to add up to their cost of production by adopting labour-intensive practices that will increase their labour costs. It could also be the case that the advanced age of such experienced farmers prevents them from adopting practices that could lead to the need for more physical strength [60]. Secured land tenure arrangements were essential to the adoption of labour-intensive CSA practices. It is acknowledged that extra labour requires extra financial capabilities and therefore, farmers want to be assured of their security of investment before committing more financial resources to their farms. This result is consistent with that of [20] who indicated that land tenure security was an important determinant of farmers adoption of sustainable farm practices such as composting.

Male farmers who have easy access to farm input markets were found to be more likely to adopt labour-intensive CSA practices. This follows the intuition that having secured the necessary farm inputs, male farmers are willing to make further investments by securing the required labour to implement labour-intensive practices especially if such practices have a proven record. The easy access of farmers to input market further increases the likelihood of adopting several labour-intensive CSA practices simultaneously. It is worth noting that easy access to the input market enhances farmers access to the necessary inputs required to facilitate the adoption of several CSA practices at the same time [61]. On the contrary, female farmers who belonged to farmer-based organisations were more willing to adopt labour-intensive CSA practices. This is because members in such organisations sometimes implement a rotational support schedule where all members work on the farm of each member on a particular day. This means that membership in a farmer-based organization reduces the burden of labour requirements associated with labour-intensive practices.

In terms of farmers' adoption of finance-intensive CSA practices, we find that farmers with large household sizes are less likely to adopt finance-intensive CSA practices. Rural households in Ghana and sub-Saharan Africa are noted for their relatively large household sizes which renders them incapable of raising enough money for the purchases of relevant inputs. It has been noted however that larger households are mostly already financially strained, leaving them with limited financial power to invest in their farms [62]. Education was also found to be essential for the adoption of finance-intensive CSA practices, especially among female farmers. We contend that female farmers who are educated may be engaged in agriculture as their main source of livelihood and therefore are willing to commit more financial resources to their farms. This may not be the case for male farmers because they may have alternative employment since the job market is more friendly to males than females.

Access to the input market was also found as an enabler to the adoption of finance-intensive CSA practices. It is important to note that farmers who develop an interest in the adopting finance-intensive CSAs may require the availability of certain farm inputs to successfully adopt and realize the benefits of their adoption, as such, having access to readily available farm inputs further enhances their rate of adoption. [63] observed that longer distance to input markets may dissuade farmers from adopting CSAs given that travelling to access inputs will add to the cost build-up of the farm. Again, extension services play a crucial role in the adoption of CSA practices, especially when such practices require that farmers commit more of their financial resources in the process of adoption. Extension agents will therefore help bridge any information gaps that may hinder farmers' adoption of finance-intensive CSA practices.

Access to extension services and being a member of a farmer-based group enhanced the adoption of finance-intensive CSA practices. It is observed that FBOs can garner support easily from government and development agencies. Additionally, they easily get access to extension services because of their organized nature. Consequently, members of FBOs tend to benefit from donor support and extension access which enhances their chances of adopting finance-intensive CSA practices. The socio-psychological factor of subjective norm was found to negatively influence the adoption of finance-intensive CSA practices. This indicates that contrary to popular belief, exerting social pressure on farmers, especially male farmers, does not enhance their likelihood of adopting technology but rather disincentivizes them not to do so.

Farmers' prior experience of climate shocks such as flooding and drought were key to their adoption of CSA practices. While female farmers who had experienced flooding were less likely to adopt finance-intensive CSA practices, all farmers who had experienced drought were more willing to adopt these CSA practices. This indicates that female farmers are more risk-averse and may not want to lose their farm investments in the event of flooding. The situation is however different from the experience of droughts. The difference in the direction of the effect of these two climate shocks is likely because CSA promise of enhancing production regardless of the availability of rain. The reason for this may be due to the fact that the occurrence of drought makes it less likely to expand a farmer's existing farm due to the absence of water [64]. However, farmers may now be more willing to invest in finance-intensive CSA practices such as drip irrigation and drought-tolerant crops which maximise water efficiency on the farm. Another key result from our study is that farmers who have their farms further from their places of residence were more likely to adopt finance-intensive CSA practices. This is because farmers want to feel that the investments made on their farms are safe from stray animals who most often destroy crops on farms in Northern Ghana [65]. It is therefore assumed that farms that are distant from residential areas are more secure from animal invasion and therefore incentivise farmers to adopt more finance-intensive CSA practices [66].

Conclusion and recommendations

Our study reveals that farmers adopt CSA practices based on their resource requirements, viewing them as complementing each other rather than competing. Despite these resource requirements, farmers are willing to adopt multiple CSA practices from different resource-based categories to maximize their synergistic effect. The main drivers of farmers' adoption behaviour of CSA practices are climatic shocks and institutional factors, which are the primary factors influencing their adoption in their respective resource-based categories. We recommend expanding access to extension services to encourage the adoption of CSA practices among dryland farmers. This can be achieved by providing mobile extension services. Additionally, the government should pursue land reforms to remove cultural land tenure security challenges. Local authorities must enhance access to input markets by organizing agricultural fairs to connect input dealers with farmers. The gender dimension of our study suggests the need for gender-specific interventions to reduce resource inequality faced by female farmers, such as gender-specific credit facilities and extension services, to enhance their capacity to adopt finance-intensive CSA practices. The main limitation of our study is assuming mutual exclusivity in categorizing the CSA practices under the three categories. Future research should explicitly capture the resource requirements of CSA practices through the data collection process to overcome this assumption.

Supplementary Information

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Supplementary Material.

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Authors' contributions
JAA: conceptualisation; formal analysis; writing–original draft; writing–review and editing. PAA: Funding acquisition; project administration; conceptualisation; formal analysis; writing–original draft; writing–review and editing. Both authors have read and approved the final manuscript.

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Data availability
The Ddata and STATA codes used for this study will be made available upon reasonable request from the corresponding author.

Declarations

Ethics approval and consent to participate
Ethical approval for this study was provided by the Humanities and Social Sciences Research Committee of the Kwame Nkrumah University of Science and Technology, Ghana. HuSSRECC subjected the protocol to a thorough review and, among other things, observed that the necessary precautions have been taken to ensure that the participants in study will be well protected from risks and other distasteful occurrences they may face in the administration of questionnaire in particular. Formal informed consent for participation was obtained verbally from each study participant after the study objectives have been interpreted to them in their local dialect. Study participants were assured of anonymity and confidentiality. The study fully adhered to the Helsinki Declaration.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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