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RESEARCH ARTICLE

Adoption of inland valley farming and rice production practices: Evidence from smallholder farmers in Côte d'Ivoire and Ghana

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Abstract

Inland valley wetlands in West African countries are considered to hold immense potential for rice-based production systems. Policies to increase rice production in inland valleys have until now not lived up to expectations. Previous studies have examined biophysical factors that affect the adoption of inland valley farming, but little empirical work has explored the socio-economic drivers of adoption. This study explores the determinants of farmers' decisions to adopt inland valley farming and rice production in Côte d'Ivoire and Ghana using probit model with data collected from 742 farmers. We show that owners of perennial tree crops are less likely to adopt inland valley farming and rice production than non-owners. This could be because perennial tree crops yield higher economic returns and provide financial stability, also for the next generation, than inland valley farming and rice production. Furthermore, farm size positively correlates with inland valley farming, but households with larger farms tend not to opt for rice production. Our results underscore that the relation between farm size and agricultural production decisions may depend on the type of agricultural practice. These results suggest that policymakers could strengthen local institutions and service providers to target specific groups of farmers when promoting inland valley farming and rice production.

Keywords: Adoption; Côte d'Ivoire; Ghana; inland valley; perennial tree crops; probit; rice production

Introduction

Sub-Saharan Africa is naturally endowed with many inland valleys, covering 85 million hectares (Rodenburg et al. 2014). While the uplands of inland valleys generally consist of good-quality agricultural soils, the valley fringes and bottoms have higher moisture availability, higher soil fertility, and higher crop and water productivity and are therefore considered to have an immense potential for crop production, notably rice-based systems (Giertz et al. 2012; Rodenburg et al. 2014). Rice is in high demand as a food crop

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in West Africa due to the increasing population and shifts in consumer preferences (Arouna et al. 2020).

Still, rice production within the West Africa region covers only 60 percent of consumption (Saito et al. 2019). Moreover, inland valleys are highly underutilized for agriculture and rice production in West Africa, as only 10–15% of the inland valley area is used for agriculture (Balasubramanian et al. 2007; Rodenburg et al. 2014) and less than 5% of suitable inland valleys are used for rice production (Danvi et al. 2016). One of the reasons why inland valleys are underutilized for agriculture and rice production is excess water in parts of the inland valleys due to poor water control facilities, such as drainage systems and bunds (Rodenburg et al. 2014).

In addition, farming in inland valleys poses health risks (Rodenburg et al. 2014; Chan et al. 2022). It can increase exposure to water-borne diseases, river blindness, sleeping sickness, and malaria, particularly in early-stage rice fields where vector densities are six times higher than in non-rice fields (Assi et al. 2013; Rose et al. 2020; Chan et al. 2022). These health risks may discourage well-off farmers from engaging in inland valley farming and rice production practices in the inland valleys. However, little is known about the socio-economic factors and constraints that shape farmers' adoption of inland valley farming and rice production.

This paper, therefore, has two objectives. First, it analyses the determinants of farmers' decisions to practice agriculture in the highly productive fringes and bottoms of inland valleys.[1] Farmers that live in inland valleys typically live and farm crops and livestock in the uplands. The second objective is to analyze the barriers and drivers of the decision to grow rice in an inland valley conditional on the adoption of inland valley farming. We collected household-level survey data from 16 inland valleys in Côte d'Ivoire and 16 in Ghana. Both countries import a large share of their rice consumption and have designated inland valley farming as a vehicle for increased food security and reduced poverty (Demont 2013). We applied a bivariate probit model to a sample of 742 randomly selected farmers (369 from Côte d'Ivoire and 373 from Ghana).

Most of the existing literature on the use of inland valleys for agriculture in West Africa analyses biophysical determinants that influence agricultural productivity, such as climate, soil types, soil fertility, rainfall, and slopes (e.g., Windmeijer and Andriesse 1993; Djagba et al. 2018; Hector et al. 2018; Djagba et al. 2019; Dossou-Yovo et al. 2019; Akpoti et al. 2021; Sawadogo et al. 2023). The few studies that include socio-economic characteristics in their analyses focus on differences between inland valleys, rather than differences between farmers, and include a very limited number of socio-economic factors (Erenstein 2006, Giertz et al. 2012, Dossou-Yovo et al. 2017, Djagba et al. 2018). Erenstein (2006) studied intensification and extensification in wetlands in Côte d'Ivoire and Mali. The author used a one-page questionnaire to collect information of limited depth from one or more key informants in 472 lowland user groups. Dossou-Yovo et al. (2017) develop a classification of inland valleys based on land use, biophysical and socio-economic data from 257 inland valleys. In each inland valley, socio-economic data were collected by means of a group meeting with 5 to 20 farmers. Djagba et al. (2018) assessed the parameters that indicate high potential for the development of rice-based systems in 499 inland valleys in Benin, Mali, and Sierra Leone. An important common finding in these studies is that distance to the nearest market is an important factor in inland valley development. Hence, we include walking distance from home to the nearest market as one of the explanatory variables in our analysis.

[1]In the remainder of the paper, whenever we write "inland valley," we refer to the highly productive fringes and bottoms of inland valleys.

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Our contribution to the existing literature is in three major directions. First, we present the first comprehensive study of socio-economic characteristics of farmers in inland valleys. We use household-level data to analyze the factors that determine whether smallholder farmers adopt inland valley farming and rice production. A better understanding of inland valley farming and rice production can help farmers' food security to reduce poverty levels in West Africa (Seck et al. 2013; Tanaka et al. 2017). We use household-level survey data from four regions in two countries with rich information on socio-economic, farm and institutional characteristics. This allows us to extend the existing literature with an in-depth analysis of the determinants of inland valley farming and rice production. Furthermore, existing studies on the socio-economic determinants of the adoption of rice production were based on group interviews or small sample sizes per inland valley, which may lead to insufficient representation of various types of farm households in the data. Second, we empirically examine the determinants of farmers' adoption of inland valley farming and, among adopters of inland valley farming, their decision to grow rice using probit models. Third, we focus on indicators for having access to capital. In particular, we provide new evidence on the role of owning perennial tree crops in agricultural production decisions.

The rest of this paper is organized as follows. Section "Conceptual framework and estimation method" provides an overview of the conceptual framework, estimation strategy, and econometric model specifications. Section "Study area, data, and description of variables" presents the material and methods, including the study area, sampling procedure, survey design and hypothesized relationships of variables. Sections "Results" and "Discussion" present the results and discussion part. The final part presents the conclusions and policy implications.

Conceptual framework and estimation method

Conceptual and empirical framework

Smallholder farmers in West Africa typically produce both for the market and for own consumption. Farmers face constraints in input and credit markets due to a lack of employment opportunities in rural areas, high transaction costs and asymmetric information. Under such conditions, farm household decisions regarding labor supply and technology adoption are determined simultaneously and are best described by a conceptual model in which consumption and production decisions are non-separable (Singh et al. 1986; Janvry et al. 1991). Such a conceptual model should also account for differences in farmers' endowments of physical, natural, financial, social, and human resources as well as in their preferences regarding production and consumption decisions.

Following Singh et al. (1986), we assume that farmers maximize their utility subject to budget constraints. In addition, we assume that farmers are constrained by their endowments of physical, natural, financial, social and human resources. Farmers will adopt inland valley farming and rice production if this gives them higher utility than alternative options. The observed outcome of adoption decisions can be analyzed using a random utility model. According to random utility theory, farmer i will adopt technology j if the utility of adoption U_{ij}^{*} is greater than the utility from non-adoption. However, since the utility is unobservable, it can be expressed as a function of observable elements in the following latent variable model and related to household, farm, institutional, environmental and location variables:

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$$U_{ij}^{*} = \beta' x_{ij} + \varepsilon_{ij} \text{ and } U_{ij} = \begin{cases} 1 & \text{if } U_{ij}^{*} > 0 \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

where U_{ij}^{*} is a dichotomous dummy variable that equals 1 if farmer i adopts and 0 otherwise; β is a vector of parameters to be estimated; x_{ij} is a vector of explanatory variables, and ε_{ij} is normally distributed error term. In this paper, an adopter of inland valley farming is a farm household that (self-reportedly) involved in farming in the inland valleys in the previous 12 months. An adopter of rice production is a farm household that (self-reportedly) involved in rice farming in the inland valleys in the previous 12 months, only for those who are involved in inland valley farming.

Estimation strategy

In this study, we model farmers' adoption decisions using two separate probit models. In the first probit model, we estimate the probability that a farmer adopts inland valley farming given the explanatory variables for the full sample and the model is specified as (Greene 2008):

$$y_{1i}^{*} = \beta' x_{1i} + \varepsilon_{1i},\ y_{1i} = 1 \text{ if } y_{1i}^{*} > 0,\ 0 \text{ otherwise} \quad (2)$$

where y_{1i}^{*} is a latent variable representing the probability to adopt inland valley farming. If $y_{1i}^{*} > 0$, farmers adopt inland valley farming; otherwise, they do not adopt inland valley farming. x_{1i} is a vector of explanatory variables; β' presents vectors of estimable model parameters; and ε_{1i} is a random error term assumed standard normal.

In the second probit model, we estimate the probability of a farmer to grow rice for those farmers who responded 'yes' to the first question, given the explanatory variables:

$$y_{2i}^{*} = \gamma' x_{2i} + \varepsilon_{2i},\ y_{2i} = 1 \textit{ if } y_{2i}^{*} > 0,\ 0 \textit{ otherwise, for } y_{1i} = 1 \quad (3)$$

where y_{2i}^{*} represents the latent variable (unobserved). If $y_{2i}^{*} > 0$, farmers choose rice crops; otherwise, they choose non-rice crops. x_{2i} is a vector of explanatory variables; γ' presents vectors of estimable model parameters; and ε_{2i} is the residual associated with the model, also assumed standard normal. Both probit models are estimated by maximum likelihood (Greene 2008). To account for potential correlation of unobserved factors within inland valleys, we compute cluster-robust standard errors. We estimate equations (1) and (2) using Stata 16.0 (StataCorp 2019).[2]

Study area, data, and description of variables

Study area

This study was part of a larger research project coordinated by AfricaRice, a CGIAR Research Center, to investigate food and nutrition security among smallholder farmers in West Africa. Data were collected in two regions in Côte d'Ivoire (Bouake and Gagnoa) and two regions in Ghana (Ahafo Ano North and Ahafo Ano South).[3] Figure 1 presents a map of the study areas.

[2]At the beginning of the estimation, an ordinary least squares regression and post-estimate variance inflation factor (VIF) were run on all variables to check whether multicollinearity issues were evident in the existing model. Our estimated VIF results suggests that multicollinearity is not an issue Kleinbaum et al. 2013. *Applied regression analysis and other multivariable methods*, Cengage Learning.

[3]In Ghana, the study areas are named districts, while in Côte d'Ivoire, they represent Sub-Prefectures; here, we use the term 'region' for simplicity. Bouake is located in the central part of Cote d'Ivoire at 7° 41' N and 5° 01' W and is located in a humid green forest agro-ecological zone (AEZ). Gagnoa is located in Côte

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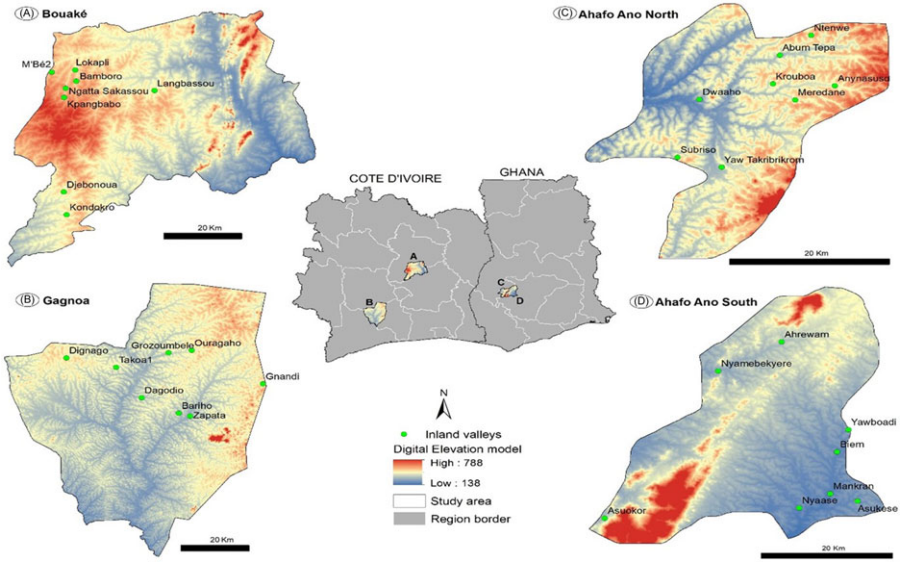

Figure 1. Map of the study area.

The selected inland valleys are located in or near the studied villages (i.e., within walking distance or accessible by (motor)bike. According to village chiefs and cooperatives, the number of household heads in the sampled inland valleys ranges from 32 to 153. In Ghana, approximately 80% of land is held under customary tenure and land use rights are assigned to individual households (Abdulai et al. 2011). The right to transfer is vested in the chief, family, lineage, or clan (Abdulai et al. 2011). In Côte d'Ivoire, customary claims are recognized by the community but not legally secure under formal land laws (Dolcerocca 2022). In both Ghana and Côte d'Ivoire, inland valleys are generally subject to the same land tenure arrangements as surrounding agricultural land. We found no evidence of distinct formal tenure rules for inland valleys from our interviews and policy documents in either country. However, their relatively higher soil fertility and water availability can give rise to informal or seasonal allocation arrangements within communities.

Access to land varies among different types of farmers (Sward 2017). Smallholder farmers often depend on rental agreements or sharecropping arrangements (Alemayehu et al. 2022). Farmers with inherited land tend to invest in long-term improvements, whereas those who rent or sharecrop may be hesitant to invest due to the uncertainty of their tenure (Diendéré and Wadio 2023; Noufé 2023). Adopting inland valley farming follows the following steps: land acquisition, initial land preparation, water management investments, and finally, depending on available resources and tenure stability, crop selection (Totin et al. 2012; Niang et al. 2017; Dossou-Yovo et al. 2022).

d'Ivoire's south-central region at 6° 7' N and 5° 57' W and is situated in a humid, dense forest area. Ahafo Ano North is located in the North-Western part of the Ashanti of Ghana at 6° 47' N and 2° 26' W. It lies in a primarily moist deciduous forest AEZ. Ahafo Ano South is located in the North-Western Ashanti of Ghana at 6° 42' N and 1° 45' W. It lies within the semi-deciduous forest belt AEZ.

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Sampling design and data collection

A multi-stage sampling procedure was used to select regions, inland valleys, and farmers. The study was conducted at the farm household level. In the first stage, four regions were purposively selected by AfricaRice and the project partner institutions to capture variation in farming systems. Within each region, a range of crops is being produced. In the second stage, a database of all inland valleys in the selected regions, including the geo-referenced location, was provided by national research institutions. Four selection criteria for inland valleys were identified based on scientific literature, information from partners, and transect walks: physical accessibility, level of development intervention, crop diversity, and water management type. We used a simple multi-criteria analysis by assigning scores to each of the four selection criteria, together with members of the national partner institutions. The scores were then summed to obtain one overall score for each inland valley, resulting in a ranking of inland valleys per region. In total, 32 inland valleys, the eight highest-scoring inland valleys in each region, were selected. In the third stage, reliable lists with information on farmers were obtained in each selected inland valley with the help of cooperatives, agricultural extension agents, and village chiefs, and a sampling frame was developed. The number of farmers selected per inland valley was proportional to the number of households per inland valley. We used a random number generator in Excel to ensure random selection. Finally, survey data were collected from 742 farmers: 369 in Côte d'Ivoire and 373 in Ghana.[4]

Household survey data were collected in July and August 2018. We used the Rural Household Multiple Indicator Survey (RHoMIS) survey tool (http://www.rhomis.org) with additional questions specific to the study context. The RHoMIS household survey tool is a standardized modular survey questionnaire and analysis package with relevant questions for our research that captures important variables in agriculture (van Wijk et al. 2020).

A survey questionnaire was prepared, pre-tested, and administered using Open Data Kit data collection computer software installed on Android-based tablets (Hartung et al. 2010). The data were collected by trained and experienced local enumerators who know the farming systems, speak both the local language and English, and have prior experience with survey work. Enumerators interviewed adult farmers. Each respondent farmer was given the option not to participate in the survey.

Description of variables and hypotheses

The selection of explanatory variables was guided by the study's conceptual framework, economic theory, and existing empirical adoption literature. The main variables can be categorized into four groups: household characteristics, access to services, physical capital and regional dummies. Table 1 provides the names and definitions of all variables.

Household characteristics

Many studies on technology adoption by smallholder farmers find that household size, age, education and gender of the farmers are key factors in decision-making (e.g., Feder et al. 1985; Ruzzante et al. 2021). Older farmers typically have more farming experience and exposure to production technologies and environments than younger ones, who often opt for non-farm activities (Kassie et al. 2015; Okeyo et al. 2020). Moreover, older farmers may

[4]Number of surveyed farmers per region: Bouake ($n = 237$), Gagnoa ($n = 132$), Ahafo Ano North ($n = 182$) and Ahafo Ano South ($n = 191$).

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Table 1. Names and definitions of variables

Variable	Description and measurement
Dependent variables	
Inland valley farming	Has the household been involved in farming in the inland valleys in the last 12 months? (1 = Yes, 0 = No)
Rice production	Has the household been involved in rice farming in the last 12 months? (1 = Yes 0 = No)
Independent variables	
Household characteristics	
Age	Age of the respondent (years)
Gender	Gender of the respondent (1 = Male, 0 = Female)
Educ	Education level of the respondent (years of schooling)
HHsize	Total family size (number)
Access to services	
Extension	Has the household been received any visits by extension officers in the last 12 months? (1 = Yes, 0 = No)
Credit	Does the household have access to credit services (1 = Yes, 0 = No)
Mktdist	Walking distance from home to the nearest market (minutes)
Physical capital	
Farmsize	Total area of land cultivated (ha)
Totincome	Total amount of cash generated by farm sales and off-farm (PPP, in USD of 2018)
Perencrop	Famer who owns perennial tree crops (1 = Yes, 0 = No)
Livestock	Livestock owned (TLU)
Region dummies	
Bouake	Farmer is from Bouake region (1 = Yes, 0 = No)
Gagnoa	Farmer is from Gagnoa region (1 = Yes, 0 = No)
AnoNorth	Farmer is from Ahafo Ano North region (1 = Yes, 0 = No)
AnoSouth	Farmer is from Ahafo Ano South region (1 = Yes, 0 = No)

have accumulated physical and social capital (Kassie et al. 2015). However, they often have short-term planning horizons, declining physical ability, and greater risk aversion, making them less open to new technologies (Kassie et al. 2015; Abegunde et al. 2020). Hence, the effect of age on the decision to adopt inland valley farming and rice production is difficult to predict a priori.

Female farmers typically face more constraints than male farmers regarding the availability of resources such as land, labor, and cash, and they face more discrimination regarding access to inputs and information, which deters them from adoption (Kassie et al. 2013). Therefore, we hypothesize that female farmers are less likely to adopt inland valley farming and rice production than male farmers.

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Farmers with better education are more likely to be capable of assessing the benefits and drawbacks of new agricultural technologies, enabling them to make informed decisions suited to their farm operations (Abdulai and Huffman 2014). However, they may be less inclined to adopt labor-intensive technologies like inland valley farming and rice production if alternative opportunities offer higher returns on their labor and capital (Kassie et al. 2013). Thus, the effect of education on inland valley farming and rice production is unclear a priori.

Household size influences labor availability and hence, farming decisions (Kassie et al. 2013). Farmers with more workers in the household have more labor for agriculture, facilitating the adoption of labor-intensive technologies like rice production while reducing hired labor costs (Feder et al. 1985; Kassie et al. 2013; Onyeneke 2017). However, farmers with large households may not have the financial resources to invest in inland valley farming or rice production since they may need the resources for other household needs (Kotu et al. 2017; Onyeneke 2017). Thus, the effect of household size on the decision to adopt inland valley farming and rice production is unclear a priori.

Access to services

Agricultural extension agents are a primary source of information for farmers regarding technology adoption in many developing countries (Manda et al. 2016). Moreover, national and local authorities support rice production (Schmitter et al. 2015; CARD 2019; AfricaRice 2020). Therefore, we hypothesize that access to extension services positively affects the adoption of inland valley farming and rice production.

Farmers in developing countries face liquidity constraints that prevent them from doing major investments, e.g., in water control infrastructure (Abdulai and Huffman 2014). Farmers who have access to credit may be able to make these investments and purchase additional farm inputs (including labor) needed to farm in inland valleys or produce rice (Rashid 2021; Ruzzante et al. 2021). Therefore, we hypothesize that access to credit and the decision to adopt inland valley farming and rice production are positively related.

Distance to the nearest market can influence farmers' decision-making since a longer distance increases input costs and reduces profitability (Teklewold et al. 2013; Huat et al. 2020). Thus, farmers farther from the nearest markets are more likely to produce for subsistence rather than for sale, making them less inclined to invest. Additionally, longer distances can limit access to information and credit institutions (Erenstein 2006; Kassie et al. 2013). Thus, we hypothesize that distance to market is negatively related to the likelihood of adopting inland valley farming and rice production.

Physical capital

As a measure of the physical capital of the household, we include farm size, a dummy variable equal to one if the household owns perennial tree crops, livestock ownership (in tropical livestock units; TLU) and total household income (in purchasing power parity; PPP) as proxies of physical capital.

Farmers with more cultivated land may have more resources to invest in the adoption of new agricultural technologies (Teklewold et al. 2013; Manda et al. 2016). However, farmers with relatively larger cultivated land may follow an extensification path, opting for less labor-intensive farming methods, whereas farmers with smaller land tend to engage in subsistence farming (Kassie et al. 2013; Hu et al. 2022). Since inland valley farming and rice production are considered to be more labor-intensive (Balasubramanian et al. 2007;

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Paresys et al. 2018), farmers with a large amount of cultivated land may prioritize upland farming and refrain from rice production (Paresys et al. 2018). Therefore, the effect of farm size on the adoption of inland valley farming and rice production is indeterminate.

The hypothesis regarding the relationship between perennial tree crop ownership and the decision to adopt inland valley farming and rice production is based on two key mechanisms: a production effect and a wealth effect. Perennial tree crops, such as cocoa, coffee, cashew nuts, and rubber, require more labor and resource allocation during the initial establishment stage of plantation (Feinerman and Tsur 2014; Asante et al. 2017). Perennial tree crops can take up to eight years before they start to yield an economic return, depending on the species (Feinerman and Tsur 2014), which can limit farmers' capacity to engage in other forms of agriculture. After the establishment period, the wealth effect starts to play a role. Perennial tree crop owners view their decision to grow perennial tree crops as an investment that provides higher returns and more financial stability and can be passed on to the next generation (Afriyie-Kraft et al. 2020; Siegle et al. 2024). Furthermore, perennial tree crops can serve as collateral, improving access to credit and reducing liquidity constraints (Asante et al. 2017; Afriyie-Kraft et al. 2020). The financial stability of perennial crops makes farmers less likely to adopt riskier and more labor-intensive practices, such as inland valley farming or rice production, which is produced for own consumption with some additional production sold on the local market (Asante et al. 2017; Afriyie-Kraft et al. 2020). Although greater wealth is typically associated with lower risk aversion, the long production cycles and delayed cash flows from perennial crops can limit short-term liquidity and tie up household labor. This inflexibility reduces incentives to diversify into more labor-intensive activities, such as inland valley farming or rice production, even when overall income levels are higher. Therefore, we hypothesize a negative correlation between ownership of perennial tree crops and the adoption of inland valley farming and rice production.

In this study, livestock ownership is measured in tropical livestock units (TLUs). In the African context, livestock can function as a form of wealth and insurance, enabling farmers to cope with shocks (Ng'ang'a et al. 2016). Livestock potentially eases credit constraints (Kassie et al. 2009), which may support investment in labor-intensive practices such as inland valley farming and rice production. Besides, livestock farming and crop production can be complementary; for instance, manure can be used for soil fertility, while crop residues can be used as livestock feed (Asante et al. 2019). From this perspective, livestock ownership may support inland valley farming and rice production. However, livestock husbandry, particularly in free grazing systems, which is common in inland valleys, requires substantial labor and land resources, which may compete with inland valley farming and rice production (Sanogo et al. 2023). Moreover, inland valleys are often seasonally flooded, limiting their accessibility and compatibility with livestock grazing (Mekuria and Mekonnen 2018; Sanogo et al. 2023). Therefore, we hypothesize that the relationship between livestock ownership and the decision to adopt inland valley farming and rice production is unclear a priori.

Total household income is the total amount of cash generated by farm sales and off-farm income. Farmers with higher total income may be able to adopt since higher income may provide farmers with greater liquidity, enabling them to invest in the necessary inputs to enhance farm productivity (Abdulai and Huffman 2014; Kassie et al. 2015). Nevertheless, inland valley farming and rice production involve labor-intensive practices and are associated with various health risks. This may discourage higher-income farmers from adopting these practices. Thus, the effect of farmers' total income on adopting inland valley farming and rice production is indeterminate.

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Table 2. Descriptive statistics of variables used in the analysis of adoption of inland valley farming

	Total sample ($n = 742$)		Inland valley farming				
			Adopters ($n = 567$)		Non-adopters ($n = 175$)		Mean diff.
	Mean	S.D.	Mean	S.D.	Mean	S.D.	t/χ^2 test statistic[a]
Inland valley farming (dependent variable; 1 = yes)	0.76	0.42	–	–	–	–	–
Household characteristics							
Age	44.93	13.71	44.31	13.63	46.93	13.83	−2.210*
Gender	0.86	0.34	0.88	0.33	0.81	0.39	4.74**
Educ	5.20	5.14	5.13	4.74	5.45	6.26	−0.726
HHsize	6.47	3.03	6.46	2.85	6.51	3.56	−0.184
Access to services							
Extension	0.36	0.48	0.38	0.49	0.29	0.45	5.46***
Credit	0.25	0.43	0.28	0.45	0.18	0.38	7.488***
Mktdist	14.20	38.20	12.99	34.27	18.33	48.83	−1.616
Physical capital							
Farmsize	2.98	4.37	3.08	4.66	2.67	3.23	1.081
Totincome (thousand)	648.6	9090.4	291.6	1592.5	1805.2	18509.4	−1.927
Perencrop	0.53	0.49	0.52	0.50	0.61	0.49	−4.257**
Livestock	0.61	2.46	0.52	1.51	0.92	4.26	−1.910
Region dummies							
Bouake	0.31	0.46	0.29	0.45	0.42	0.49	−10.063***
Gagnoa	0.17	0.38	0.20	0.40	0.10	0.30	8.817***
AnoNorth	0.24	0.43	0.26	0.44	0.21	0.41	1.757
AnoSouth	0.25	0.43	0.25	0.43	0.27	0.45	0.279

Note: S.D. is standard deviation. */**/*** significant at 10/5/1% level.
[a]*t*-test and χ^2-test are used for continuous and categorical variables, respectively.

Regional dummies

Environmental, cultural, and institutional factors are likely to be similar for all farmers in the same region but may differ between regions. Since these factors are not fully captured by the other variables, we include region dummies in the models (Wauters and Mathijs 2014; Danso-Abbeam and Baiyegunhi 2017; Ojo and Baiyegunhi 2020).

Descriptive statistics

Table 2 presents the descriptive statistics of the key variables of interest. In our sample, about 76% of farmers are engaged in inland valley farming. The average age of the

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respondents is 45 years. Additionally, the survey sample consisted primarily of male-headed households, with 86% of the respondents falling into this category. The average education level of the respondents is 5 years. The average household size of the respondents is 6.5 members, with an average farm size of 3 hectares. About 53% of households own perennial tree crops. Access to extension and credit services is limited, with only 36% and 25% of households having access to these services, respectively. This result indicates that credit and extension services are not widely available. The average walking distance from home to the market is about a quarter of an hour. Table 2 further presents the differences in the means of all independent variables between adopters and non-adopters of inland valley farming. The results indicate that adopters differ significantly from non-adopters in terms of age and gender. The share of households that own perennial tree crops is larger for non-adopters than for adopters. The share of households with access to extension services and credit is larger for adopters than non-adopters.

Table 3 presents an overview of descriptive statistics and statistical significance tests on the equality of means for rice production for only households that adopt inland valley farming. The table shows that 42% of households have been involved in rice production in the preceding 12 months. Households that opted for rice production have households that are, on average, younger than households that do not grow rice. Furthermore, on average, households that choose to grow rice have smaller farms and are less likely to grow perennial tree crops.

In the regressions, we include the natural logarithm of both farm size and total income rather than their levels due to their skewed distributions.

Results

Table 4 presents the results from the probit regression analyses. The probit regression in column (a) presents the results for the adoption of inland valley farming using the full sample of 742 households. The probit regression in column (b) estimates the adoption of rice production for those farmers who adopted inland valley farming (567 households). The regression diagnostic statistics indicate that both models are well-specified and statistically robust. For the full-sample model of inland valley farming adoption, the Wald chi-square test ($\chi 2 = 123.63$, $p < 0.01$) indicates that the explanatory variables jointly and significantly explain the variation in adoption. Likewise, the rice production model, estimated on the subsample of inland valley farming adopters, shows a strong overall fit ($\chi 2 = 160.03$, $p < 0.01$).

Determinants of adoption of inland valley farming

Column (a) of Table 4 presents the regression results of the determinants of farmers' adoption decision of inland valley farming. The results show that the decision to adopt inland valley farming is negatively and significantly associated with the age of the household. As expected, male farmers are more likely to adopt inland valley farming than female farmers. Access to credit services is positively associated with the adoption of inland valley farming, while the distance to the market has a negative correlation. The results also reveal that the size of cultivated land has a positive correlation, while ownership of perennial tree crops and livestock ownership is negatively correlated with the adoption of inland valley farming.

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Table 3. Descriptive statistics of the variables used in the analysis of adoption of rice production, only for households that adopted inland valley farming ($n = 567$)

	Sample of adopters of inland valley farming ($n = 567$)		Rice production				
			Adopters ($n = 240$)		Non-adopters ($n = 327$)		Mean difference
Variable name	Mean	S.D.	Mean	S.D.	Mean	S.D.	t/χ^2 test statistic[a]
Rice farming (dependent variable; 1 = yes)	0.42	0.49	–	–	–	–	–
Household characteristics							
Age			42.66	13.40	45.52	13.68	−2.48**
Gender			0.88	0.33	0.88	0.33	0.01
Educ			4.82	4.77	5.36	4.72	−1.34
HHsize			6.19	2.62	6.66	3.01	−1.92*
Access to services							
Extension			0.46	0.50	0.33	0.47	10.07***
Credit			0.32	0.47	0.25	0.44	2.70
Mktdist			10.87	23.69	14.54	40.27	−1.26
Physical capital							
Farmsize			2.30	2.27	3.65	5.76	−3.45***
Totincome (thousand)			274.21	1589.0	304.0	1596.7	−0.22
Perencrop			0.32	0.47	0.66	0.47	−66.71***
Livestock			0.48	1.28	0.55	1.66	−0.52
Region dummies							
Bouake			0.29	0.45	0.29	0.45	0.01
Gagnoa			0.25	0.43	0.17	0.37	5.19***
AnoNorth			0.24	0.43	0.27	0.45	−0.87
AnoSouth			0.23	0.42	0.27	0.44	−0.17

Note: S.D. is standard deviation. */**/*** significant at 10/5/1% level.
[a]*t*-test and χ^2-test are used for continuous and categorical variables, respectively.

Determinants of adoption of rice production

The estimates of the determinants of farmers' decision to grow rice for only farmers who adopted inland valley farming are presented in Table 4 of column (b). The results reveal that the age of the household is negatively and significantly correlated with the adoption of rice production. As expected, rice production is positively and significantly correlated with access to extension services, while distance to market has a negative correlation. The results also show that the size of cultivated land and ownership of perennial tree crops are negatively and significantly associated with the decision to grow rice.

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Table 4. Probit model estimates of adoption decision of inland valley farming and rice production

	Adoption of inland valley farming (full sample $N = 742$)		Adoption of rice production (subsample of inland valley farming adopters, $N = 567$)	
	(a)		(b)	
Explanatory variables	Coefficient	S.E.	Coefficient	S.E.
Household characteristics				
Age	−0.009*	(0.005)	−0.007*	(0.004)
Gender	0.282**	(0.114)	−0.015	(0.157)
Educ	−0.012	(0.011)	−0.008	(0.014)
HHsize	0.016	(0.020)	0.023	(0.022)
Access to services				
Extension	0.236	(0.159)	0.645***	(0.153)
Credit	0.438**	(0.177)	0.075	(0.179)
Mktdist	−0.002*	(0.001)	−0.005***	(0.002)
Physical capital				
lnFarmsize	0.230**	(0.108)	−0.282**	(0.112)
Perencrop	−0.259*	(0.139)	−1.065***	(0.133)
Livestock	−0.050*	(0.029)	0.018	(0.038)
lnTotincome	−0.006	(0.017)	−0.026	(0.016)
Region dummies				
Bouake	−0.272	(0.346)	0.492	(0.301)
Gagnoa	0.347*	(0.187)	0.790***	(0.260)
AnoNorth	0.250	(0.199)	−0.173	(0.307)
Constant	0.643*	(0.369)	0.609	(0.410)
Regression diagnostics				
Log_lik	−376.034		−320.555	
Wald (χ^2)	123.631		160.025	
χ^2 (df)	14		14	

Note: S.E. is the Standard errors clustered at inland valley levels in parentheses. */**/*** statistically significant at 10/5/1% level. The reference region is Ahafo Ano South.

Robustness checks

We further assess the robustness of the results using two different subsamples (*see Supplementary Material* – Appendix B*)*.

First, we perform a probit regression analysis of the adoption of inland valley farming with the sub-sample excluding observations in which non-household heads were interviewed, yielding 674 observations instead of 742 (Table B1, *column a*). Second, we perform a probit regression analysis of rice production adoption, restricting the sample to

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household heads who adopt inland valley farming, which yields 516 observations instead of 567 (Table B1, *column b*). This restriction excludes non-head respondents who may not have full decision-making or complete knowledge about household farming choices. This robustness check assesses whether differences in information between groups of respondents affect our findings.

The results (Table B1, *column a and b*) are largely consistent with those from the full sample. Age remains negatively associated with the probability of both inland valley farming and rice production adoption. Gender continues to exert a positive and highly significant effect on inland valley farming adoption and remains insignificant for rice production adoption. Access to credit is positively and significantly associated with inland valley farming, while it remains insignificant for rice production adoption. Extension services are positive but not significant for inland valley adoption, yet strongly positive and significant for rice production adoption. Market distance consistently exerts a negative and statistically significant correlation with inland valley farming and rice production adoption. Among the physical capital variables, farm size continues to be positively and significantly associated with inland valley farming and negatively and significantly associated with rice production adoption. Perennial crop ownership is negatively and significantly associated with both inland valley farming and rice production adoption. Livestock ownership remains negatively associated with inland valley farming adoption, while total household income becomes weakly significant and negative in the rice production adoption model, a finding not observed in the main results. Overall, the results of the robustness check indicate that it does not affect our main conclusions.

Discussion

Household characteristics

In subection "description of variables and hypotheses" we hypothesized that female farmers are less likely to adopt inland valley farming and rice production. We did not derive clear hypotheses for the role of age, education, and household size.

Our findings suggest that older farmers are less likely to adopt inland valley farming and rice production. This result may be linked to the labor-intensive nature of this agricultural practice, given the potential decline in the physical capability of older farmers. Moreover, it is consistent with the notion that older farmers often exhibit shorter planning horizons, potentially rendering them more risk-averse. This is particularly relevant in the inland valleys, where these agricultural practices are connected to health risks, ultimately impacting production. This result is also in consonance with earlier work on adoption (e.g., Kassie et al. 2015; Abegunde et al. 2020; Ojo and Baiyegunhi 2020).

Our findings confirm the hypothesis that female farmers are less likely to adopt inland valley farming than their male counterparts. This is consistent with the findings of some previous studies (e.g., Kassie et al. 2013; Manda et al. 2016). This may reflect that women have less access to critical resources, such as land, education, training, and information on agricultural practices, as emphasized in studies by Bedeke et al. (2019) and Ndiritu et al. (2014). However, we do not find a statistically significant relationship between gender and rice production. This is likely attributed to the fact that access to critical resources, which may hold women back from adopting inland valley farming, does not seem to play a role when it comes to the adoption of rice production. Across West Africa, women's adoption of new farming practices is often constrained by limited access to land, credit, and extension services (e.g., Theriault et al. 2017). In rice production, however, social norms and cropping systems sometimes grant women clearer roles and better access to

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communal resources in West Africa (e.g., Burkina Faso, Côte d'Ivoire, Madagascar, Sierra Leone), narrowing these gaps (Kinkingninhoun Medagbe et al. 2020).

Education and household size do not seem to affect the likelihood of inland valley farming or rice production. This reflects the fact that the literature finds, for each variable, opposing effects when it comes to farming decisions and technology adoption.

Access to services

We expected access to extension services to positively contribute to both the adoption of inland valley farming and rice production. However, we only find evidence for rice production adoption, not for inland valley farming. These results are in line with previous research on adoption (Abdulai and Huffman 2014; Schmitter et al. 2015; AfricaRice 2020; Ruzzante et al. 2021). The results suggest that farmers who have access to extension services are more inclined to engage in rice production, implying that extension services provide essential support in terms of technical assistance and market information related to rice production in the inland valleys. The coefficient for having received extension services in the past twelve months is not significant for the adoption of inland valley farming. This suggests that smallholder farmers are already familiar with inland valley farming, making them less reliant on support from extension services.

We hypothesized that access to credit would increase the likelihood of both inland valley farming and rice production. The hypothesis is confirmed for inland valley farming, which suggests that liquidity constraints play a role in the investments required for inland valley farming. Notably, this finding aligns with prior research on the role of credit in the adoption of new farming techniques (e.g., Teklewold et al. 2013; Abdulai and Huffman 2014; Ojo and Baiyegunhi 2020; Ruzzante et al. 2021). However, we do not find a statistical relationship between access to credit and rice production. This could be due to the government's provision of seeds, fertilizer, and small equipment as incentives to rice farmers (Fofana et al. 2014; Yuan et al. 2024).

Distance to market was expected to be negatively associated with the adoption of inland valley farming and rice production. Consistent with previous research work on adoption (e.g., Erenstein 2006; Kassie et al. 2013; Teklewold et al. 2013; Djagba et al. 2018; Muriithi et al. 2018; Tey and Brindal 2023), we find that distance to market has a negative correlation with both the adoption of inland valley farming and the adoption of rice production, though evidence is less strong for the former. This result could be that a longer distance to the market increases the costs of inputs and selling outputs, leading farmers to produce for their own consumption rather than sell to the local market.

Physical capital

As indicated in section "Physical capital", for farm size, livestock, and income, we found that there are both factors that increase the likelihood of adoption of inland valley farming and rice production and factors that decrease these likelihoods. Hence, we were unable to formulate clear hypotheses for these variables. We hypothesized that ownership of perennial crops would reduce the likelihood of adoption of inland valley farming and rice production.

Farm size has a positive and statistically significant relationship with the adoption of inland valley farming. A possible explanation could simply be the fact that, given the amount of land that an individual farmer has in the uplands, starting farming activities in inland valleys implies an increase in cultivated area compared to a farmer who does not adopt inland valley farming. In addition, the size of cultivated land is an important

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measure of household wealth and resource availability, while the adoption of inland valley farming necessitates the availability of resources for the deployment of technologies such as power tiller equipment and small-scale mechanization. The result agrees with the empirical findings of Manda et al. (2016) and Teklewold et al. (2013).

However, farm size is negatively and significantly correlated with the adoption of rice production, suggesting that farmers with more cultivated land are less likely to grow rice. While this finding may be surprising from the perspective of the agricultural technology adoption literature, it is in line with Chan et al. (2022), who indicated that at the early stages of rice production, malaria vector densities are high in inland valleys, making rice production risky. Thus, wealthier farmers, in terms of farm size, may prefer alternative crops, while households with small farms may prioritize rice production, as rice is a staple food.

We find that ownership of perennial tree crops is negatively associated with both inland valley farming and rice production. One possible explanation for this result may be the higher returns and financial stability as compared to other crops, and the fact that perennial tree crops can be passed on to the next generation. This agrees with Afriyie-Kraft et al. (2020), who indicated the economic superiority of perennial crops over other annual crops, and Asante et al. (2017), who emphasized the financial stability provided by perennial tree crops. Another reason may be that, unlike annual crop cultivation, the initial stages of perennial crop cultivation are more labor-intensive than alternative crop cultivation, which leaves farmers with limited time to engage in alternative farming activities such as inland valley farming and rice production. This result is also in agreement with (Feinerman and Tsur 2014; Asante et al. 2017). Moreover, from a welfare perspective, even though perennial tree crops offer greater long-term profitability and stable income, rice production provides more frequent harvests and short-term cash flow critical for household food security. This trade-off means that, although perennial crops are lucrative, rice production remains important for reducing food vulnerability and dependency on market purchases.

We find that livestock ownership is negatively correlated with the adoption of inland valley farming, but there is no statistically significant association with rice production. This result supports the notion that livestock husbandry, particularly under free grazing systems common in the study areas, competes with inland valley farming for land and labor resources (Sanogo et al. 2023). Farmers with larger livestock holdings may prioritize grazing areas and allocate household labor to livestock management rather than investing in labor-intensive inland valley cultivation.

We fail to find a statistically significant correlation between total household income and the adoption of inland valley farming and rice production. This may reflect the fact that the literature finds opposing effects when it comes to farming decisions and technology adoption.

Conclusion and policy implications

Inland valleys remain significantly underutilized for agriculture and rice production in West Africa. This paper examines the determinants of farmers' decisions to adopt inland valley farming and to adopt rice production, using cross-sectional data collected from a sample of 742 smallholder farmers in the inland valleys of Côte d'Ivoire and Ghana. Overall, the findings of this study indicate the important role of household characteristics, access to services, and the availability of physical capital in the adoption of inland valley farming and rice production.

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This study provides new evidence into the importance of perennial tree crop ownership in agricultural adoption. Perennial crops provide superior economic returns, long-term benefits for successive generations and financial stability. Such context-specific information helps policymakers identify target farmers for promoting inland valley farming and rice production.

Our findings carry several policy implications. First, the analysis provides new evidence on the role of owning perennial tree crops in agricultural adoption in the inland valley context. Ownership of perennial tree crops is negatively associated with both inland valley farming and rice production. Extension services could be more effective by focusing on farm households who do not own perennial tree crops.

Second, farm size was positively correlated with inland valley farming but negatively correlated with rice production. The reason may be that farmers with small landholdings may have no option rather than prioritize rice production to meet their family's food needs since rice is a staple food crop. As such, it underscores that farm size has a differential effect on adoption, depending on the type of agricultural practices. Policymakers and extension workers could factor in the effect of this physical capital variable.

Third, since access to extension services has a strong positive association with the adoption of rice production, policies and strategies of governments fostering rice production could be geared towards strengthening the agricultural extension systems. Furthermore, enhancing farmers' access to credit is identified as a potential avenue for accelerating the adoption of inland valley farming. Therefore, policymakers could consider implementing measures such as expanding rural microfinance markets to improve farmers' access to credit services.

Fourth, as female farmers show lower adoption of inland valley farming, policymakers could consider measures that ensure women have greater access to complementary inputs, such as land, labor, and extension services. It is crucial to recognize that women may face unique challenges and constraints that hinder their ability to engage in farming practices.

Fifth, as farmers with more livestock show lower adoption of inland valley farming, policymakers should design measures that address the potential trade-offs between livestock husbandry and valley cultivation. This could include promoting controlled grazing systems, offering incentives for integrated crop livestock practices, or targeting farmers with fewer livestock who may face fewer barriers to adoption.

Finally, our study is not without limitations. Our findings are derived from a representative sample of farmers in inland valleys in four regions of two West African countries. However, West Africa's inland valley farming and rice production practices have unique dynamics and challenges, and it is essential to recognize that these features do shape agricultural adoption decisions. Although our results provide interesting new insights about the adoption decisions of inland valley farming and rice production in West Africa, more research is needed in other regions of the world to draw more general conclusions about inland valley farming.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/age.2025.10018

Data availability statement. The data that support the findings of this study are available from the corresponding author, [T.A], upon reasonable request.

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