Multifunctionality of inland valley wetlands for food security in the rice-based farming system of Côte d'Ivoire and Ghana



Tesfahun Alemayehu Belew

Propositions

1. Biodiversity conservation in the inland valleys of West Africa depends on farmers' livelihood interests.
   (this thesis)
2. Rice-focused investment in West African inland valleys disregards farmers' heterogeneous land use preferences.
   (this thesis)
3. Opinion leaders influence community understanding of climate change more than scientists.
4. Generative Artificial Intelligence reshapes curricula in universities.
5. The absence of local scientific input is a major cause of GMO hesitancy in Africa.
6. Space exploration receives greater priority than Earth's environmental protection.
7. Social isolation definitely outweighs the impact of COVID-19 on human health.
8. The spread of health information on social media increases societal confusion.

Propositions belong to the thesis, entitled

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Wageningen, 28 September 2026

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Chapter 1

General Introduction

1.1 Background

Inland valley wetlands play an important role in supporting the livelihoods of many households in West Africa. These wetlands are increasingly used for rice-based farming to address food security challenges. Beyond rice production, inland valleys have huge potential for growing high-value fruits, cash crops, other cereals, and fodder crops (Balasubramanian et al., 2007). Besides provisioning services and food production, inland valleys provide other key ecosystem services that are important for farmers' livelihoods and are biodiversity hotspots (e.g., Roberts, 1988; Adams, 1993; Rodenburg et al., 2014). However, the contributions of the diverse uses and benefits of inland valley wetlands to food security are often overlooked.

Thus, the main objective of this thesis is to obtain an improved understanding of how the multifunctional potential of inland valley wetlands contributes to food security at the national level in Côte d'Ivoire and Ghana. To achieve this main objective, four specific research questions have been developed. (1) What are the characteristics of inland valley farming systems in Côte d'Ivoire and Ghana, and what is the relevance of ecosystem services for smallholder farmers in these regions? ***(Chapter 2)***, (2) What key determinants influence farmers' decisions to adopt inland valley farming and rice production practices? ***(Chapter 3),*** (3) What alternative land use and development options in inland valley agriculture are attractive to farmers, and how do they make monetary trade-offs between specific attributes of these options? And what factors drive potential heterogeneity in farmer preferences? ***(Chapter 4)***, and (4) How important are wild foods for farm households' food security (kilocalories) and poverty reduction (income) in the inland valley wetlands of Côte d'Ivoire and Ghana, and what factors influence farm households' wild food collection? And what is the relationship between wild food collection and farmers' awareness of provisioning ecosystem services? ***(Chapter 5)*.**

Smallholder-based farming is the primary source of livelihood for farm households in the inland valleys of West Africa. Farm households in this region largely depend on crop production for food and income (Kuivanen et al., 2016). Rice is a fundamental and strategic staple food crop that contributes to food security in West Africa (del Villar and Lançon, 2015; Soullier et al., 2020).

It is the most consumed crop, and its consumption has increased more rapidly than that of any other staple food crop (Seck et al., 2012; Arouna et al., 2017). This rapid increase is driven by population growth, dietary preferences for rice, and urbanisation. West Africa accounts for 65% of the total rice production and covers 70% of the rice area in sub-Saharan Africa (SSA) (Soullier et al., 2020). Despite a favourable rice-growing environment, rice self-sufficiency and food security remain challenging in most West African countries. The domestically produced rice meets only 60% of the consumption needs (Saito et al., 2019); around 40-50% of rice is imported to satisfy the demand (Rodenburg and Saito, 2022). Côte d'Ivoire, Nigeria, Senegal, and Ghana are the major rice importers (Demont et al., 2017).

In West Africa, food and nutrition insecurity is among the highest in SSA. It is defined as the lack of access to sufficient, safe, and nutritious food necessary for a healthy and active life (FAO, 1996). About 270 million people, which is equivalent to 62% of the West African population, are experiencing food insecurity (FAO, 2024). The number of undernourished people has risen from 33.1 million in 2005 to 70.4 million in 2023, equivalent to 16% of the population in 2023 (FAO, 2024). Food and nutrition insecurity is expected to worsen as food demand is projected to triple over the next thirty years (Van Ittersum et al., 2016; Yuan et al., 2024). Furthermore, climate change has fueled the problem.

In response to these challenges, government policy in West African countries is geared toward rice self-sufficiency through local production (Demont, 2013; CARD, 2019). Rice production has increased from 2.2 million tons in the 1960s to 12.7 million tons in 2018, driven primarily by the expansion of rice acreage (Soullier et al., 2020; Saito et al., 2023). However, yield increases through rice intensification have contributed little to production, partly due to low adoption of improved agricultural practices (Kolleh et al., 2025) and unsustainable intensification (Pretty and Bharucha, 2014).

Efforts to increase rice production through area expansion and intensification have not led to the necessary food self-sufficiency and food security in the region. However, further expansion would convert natural ecosystems, thereby threatening the ecosystem services on which agricultural production depends (van Loon et al., 2019; Yuan et al., 2024). These limitations indicate the need to explore alternative approaches that extend beyond standard increases in rice production. However, inland valley systems are

complex and heterogeneous, and their current use is poorly understood, requiring a more integrated understanding of the farming system. Thus, this thesis provides a detailed analysis of the farming systems, which is needed to better understand the complex and variable system for future use (Ibrahim et al., 2021; Dossou-Yovo et al., 2022; Rodenburg and Saito, 2022).

1.2 Inland valley in West Africa

An inland valley can be defined as a seasonally flooded wetland comprising a valley bottom and hydromorphic fringes up to the upper crests (Andriesse and Fresco, 1991). Inland valleys occupy 85 million hectares, equivalent to 36% of the wetland area in SSA (Andriesse, 1986). In West Africa, inland valleys occupy 22–25 million hectares, equivalent to 10–25% of the inland valley wetlands in SSA (Andriesse et al., 1994). Inland valleys are characterised mainly by favourable hydrological regimes and soil fertility (Andriesse and Fresco, 1991). Precipitation is the only water source on the crests and uplands of the inland valley. The hydromorphic fringes rely on both rainfall and groundwater, while for the valley bottom, precipitation, groundwater, surface flow, and flooding are the primary sources of water (Andriesse and Fresco, 1991). The soil on the upper crests of the inland valley is characterised by high runoff and low water-holding capacity. In contrast, hydromorphic fringes and valley bottoms have relatively more fertile and heavily textured soils (Andriesse and Fresco, 1991).

The fringe and valley bottom offer a conducive environment for crop production, particularly for rice-based production systems, due to relatively secure water availability and higher soil fertility (Rodenburg et al., 2014). Rice-based farming systems encompass more than just rice cultivation. The sustainable use and development of inland valleys require consideration of the multiple uses and benefits in agricultural systems, and farmers' preferences and constraints, which are essential for achieving food security. The use and development of inland valleys into rice-based farming systems can be hampered by a lack of consideration for the multiple uses and benefits, an understanding of farmers' preferences and constraints, and low technology adoption rates. For these reasons, inland valleys represent vast, largely underutilised areas (Rodenburg et al., 2014).

1.3 Inland valley farming and rice production practices

Research and development institutions, together with their partners and public bodies, have implemented strategies to boost inland valley farming (Andriesse et al., 1994; AfricaRice, 2020). Over the past three decades, these efforts have resulted in the expansion of inland valley farming. However, the use of inland valleys for farming remains far below expectations, with only 10-15% being utilised for agriculture (Balasubramanian et al., 2007). This underutilization is partly due to challenges in managing excess water in certain parts of the inland valleys (Rodenburg et al., 2014) and health risks associated with waterborne diseases such as schistosomiasis and malaria (Andriesse et al., 1994; Chan et al., 2022).

Studies indicate that improved farming practices and technologies, such as inland valley water management techniques and stress-tolerant, high-yielding crop varieties, can boost agricultural production and contribute to food security in SSA (Pan et al., 2018). In West Africa, new knowledge, practices, and technologies have been widely implemented to improve farmers' productivity and livelihoods (Rodenburg and Saito, 2022). The adoption rate of these technologies and practices has increased over the years (e.g., Arouna et al., 2017).

However, despite the ample potential of inland valleys for agriculture and the number of technologies, smallholder farmers' adoption of these improved technologies has been slow and is far below expectations. For instance, less than 5% of suitable land in inland valleys is used for rice cultivation (Balasubramanian et al., 2007; Darvill and Lindo, 2016). The low adoption of inland valley farming and rice production practices requires an understanding of the biophysical, socio-economic, farm, and institutional determinants that drive farmers' adoption decisions. These insights can support the policy efforts aimed at food security in the region.

1.4 Ecosystem services in the inland valleys

Inland valleys provide diverse regulating, supporting, and cultural ecosystem services that benefit local communities, in addition to the provisioning services (MEA, 2005). They are also important habitats for animal and plant species and contribute to biological diversity (Adams, 1993; Sakané et al., 2011). However, globally, wetlands, including inland valley wetlands, are showing a rapid decline in these services due to changes in

land use (Wu, 2014). In West Africa, studies indicate that crop production should prioritise areas with high development potential while minimising risks to ecosystem services (Rodenburg et al., 2014). Nevertheless, government policies and research efforts have promoted inland valleys for rice production. The various benefits to local communities have often been ignored in policy planning, implementation, and research (Wood et al., 2013). This, in turn, leads to suboptimal management of wetlands for providing diverse ecosystem services and supporting local communities' livelihoods (Speelman et al., 2015).

Research shows that rice cultivation in inland valleys negatively impacts biodiversity and the provision of ecosystem services (Behn et al., 2018; Djagba et al., 2018a). This affects the availability of other provisioning services and wild foods that most people, particularly those experiencing poverty, could use to supplement their diets and generate income. For instance, wild foods are important sources of energy, protein, and micronutrients for the most vulnerable globally (Bharucha and Pretty, 2010).

Balancing rice cultivation with the delivery of other ecosystem services is becoming increasingly critical to prevent the degradation and loss of functionality in inland valleys. Achieving such a balance starts with understanding farmers' awareness of ecosystem services and how these services sustain their livelihoods. This understanding could be useful in designing appropriate inland valley use policies to ensure that critical ecosystem services contribute to farmers' well-being and coexist with ecosystem conservation for sustainable food production.

1.5 Study rationale

The 2008 world cereal price surge triggered a food shortage crisis and social instability in most West African countries (Mendez del Villar and Lançon, 2015). In response, the governments of these countries and development partners reoriented their agricultural development strategies and policies toward increasing rice production in the inland valleys (Andriesse et al., 1994; Giertz et al., 2012; Demont, 2013; Rodenburg et al., 2014). Immediately after the crisis, the focus on increasing rice production, which meant thatlittle attention was given to their diverse uses and benefits, including ecosystem services. However, agricultural expansion often negatively affects biodiversity (Djagba et al., 2018a) and ecosystem stability in inland valleys (Nyamadzawo et al., 2015). Such

expansion may also conflict with other critical ecosystem services (e.g., supporting services), which can, in turn, affect agricultural production.

Existing studies have focused on rice farming systems (Touré et al., 2009; Demont and Ndour, 2015) rather than on farm and farming systems at the level of inland valleys from broader perspectives. This emphasis on rice production has limited attention to the broader functions and services provided by inland valley systems. An in-depth understanding of the farming systems in inland valleys in West African countries is, therefore, still lacking. This has hampered the design of suitable interventions and the provision of diverse resource-use strategies for individual inland valleys.

This thesis addresses the knowledge gaps in different ways. *First*, it offers an in-depth assessment of farm and farming systems at the inland valley scale. Specifically, this assessment examines the agricultural and institutional indicators and farm households' food security status. Additionally, smallholder farmers' perceptions of the relevance of ecosystem services provided by inland valleys.

For example, there are large differences among farmers regarding production system attributes and demography (e.g., resource endowments, labour, household size), crop production practices, and levels of awareness of ecosystem services. Thus, understanding the diversity of farmers' socio-economic and biophysical conditions may help in the development of improved agricultural practices and resource-use strategies for inland valleys.

Second, the determinants influencing farmers' decisions to adopt inland valley farming and rice production practices are identified. Despite the policy and research efforts and obvious benefits of improved agricultural practices for farmers, the adoption of such improved agricultural practices for inland valley farming and rice production is still low in West Africa.

Most of the existing research on the use of inland valleys for agriculture in West Africa focuses on the analyses of biophysical determinants that influence agricultural productivity, such as climate, soil types, soil fertility, rainfall, and slopes (e.g., Djagba et al., 2018b; Dossou-Yovo et al., 2018; Sawadogo et al., 2023). The low adoption of inland valley farming and rice production practices is partly because of inadequate water management technologies. Moreover, farming in inland valleys poses health risks (Rodenburg et al., 2014; Chan et al., 2022).

However, relatively little empirical work has been done to examine the socio-economic drivers that shape farmers' adoption decisions of inland valley farming and rice production. Few studies have assessed these socio-economic determinants, but these studies were based on group interviews (e.g., Djagba et al., 2018a) or small sample sizes per inland valley (e.g., Giertz et al., 2012; Dossou-Yovo et al., 2017). A better understanding of the determinants of farmers' adoption decisions of inland valley farming and rice production could, therefore, help design the dissemination of these practices at the local, national, and regional levels. Such adoption and dissemination could, in turn, contribute to improving farmers' food security in West Africa.

The *third* research gap I address is the limited empirical evidence on farmers' preferences for alternative inland valley uses and development options. Studies indicate that policies and technological interventions are more likely to be sustainable and bring the expected change when aligned well with farmers' preferences (Meijer et al., 2015; Brosseau et al., 2021).

However, existing policy and research efforts provide limited empirical evidence on how farmers evaluate alternative inland valley configurations and the trade-off associated with the different inland valley attributes, particularly in relation to long-term sustainability (Wood et al., 2013; Rodenburg et al., 2014). Specifically, there is limited understanding of farmers' preferences for the diverse inland valley use attributes, the trade-offs between these use attributes, and the potential heterogeneity in preferences, as well as the factors driving these preferences (Ortega et al., 2016; Dam et al., 2021).

Furthermore, agricultural research and policies in the inland valleys have primarily focused on rice production, with little to no attention given to growing other crops, biodiversity benefits, and the trade-offs between different inland valley attributes (Diagne et al., 2013; Brosseau et al., 2021). This narrow research and policy focus may not reflect and align with farmers' actual preferences, as evidence suggests that farmers may prefer diversification, including the cultivation of other crops (van Oort et al., 2016; Huat et al., 2020; Brosseau et al., 2021). A scientific assessment of farmers' preferences towards rice productivity and other attributes of inland valleys is, therefore, important. Such an assessment can guide the design of context-specific and sustainable inland valley management strategies and contribute to the success of future policies and development efforts.

Fourth, this thesis provides novel empirical evidence on the contribution and monetary quantification of wild foods to household food security and income in the inland valleys of Côte d'Ivoire and Ghana, and the factors influencing their collection. Inland valley wetlands in these countries are biodiversity hotspots that provide a variety of wild foods, which supply essential nutrients, generate income, and act as a safety net during agricultural shortfalls, thereby enhancing livelihood resilience (Brashares et al., 2011; Rodenburg et al., 2014). Unlike many cultivated crops, wild foods often exhibit greater resilience to climate change and can support adaptation strategies for smallholder farmers (Chivandi et al., 2015; Paumgarten et al., 2018).

However, most food security studies that measure food availability (FA) in kilocalories per male adult equivalent per day (kcal MAE^{-1} day^{-1}) have focused on contributions from on-farm production, purchased foods, and farm-based income, while largely neglecting wild foods (Frelat et al., 2016; Hammond et al., 2017; Lopez-Ridaura et al., 2018). The exclusion of wild foods prevents their integration into food security policy and biodiversity management strategies. Furthermore, the socio-economic, institutional, and seasonal (lean vs. good season) drivers of wild food collection remain underexplored, as does the link between wild food collection and the provisioning ecosystem services of inland valleys.

An understanding of the role of wild foods in food security, income generation, and ecosystem service provision is critical for designing policies that balance food security objectives with biodiversity conservation and for promoting sustainable inland valley management (Sunderland, 2011; Becquey et al., 2012; Hickey et al., 2016).

1.6 Study regions

This study is part of a larger research project, "Capitalising on the inland valley potential for food and nutrition security for smallholder farmers in West Africa (CIPA)," coordinated by AfricaRice (a CGIAR Research Centre), to investigate the inland valley potential for food and nutrition security for smallholder farmers in West Africa. Côte d'Ivoire and Ghana were selected to implement the project within which this PhD study was conducted. In both countries, more than 70% of the population's livelihoods depend on agriculture. These countries have vast land areas of inland valley wetlands suitable for rice-based farming (Diagne et al., 2013), yet they are among the top four rice-importing countries in West Africa (Demont et al., 2017).

The study sites were Bouaké and Gagnoa in Côte d'Ivoire and Ahafo Ano North and Ahafo Ano South in Ghana. The study sites belong to humid and subhumid agro-ecological zones (AEZ) with contrasting characteristics. Bouaké is located in the central part of Côte d'Ivoire at 7° 41' N and 5° 01' W, with annual rainfall ranging from 1300 to 2300 mm. Gagnoa is located in Côte d'Ivoire's South-central area at 6° 7' N and 5° 57' W. The annual rainfall ranges from 1400 to 2500 mm. Ahafo Ano North is located in the northwestern part of Ghana at 6° 47' N and 2° 26' W. The mean annual rainfall is 1750 mm. Ahafo Ano South is located in northwestern Ghana at 6° 42' N and 1° 45' W, with a mean annual rainfall between 1700 and 1850 mm. In all the study sites, agriculture is the main source of livelihood for the smallholder farmers. Rice is one of the most consumed cereal crops in the study sites, and it is mainly grown in the inland valley wetlands.

1.7 Research approach

The analyses presented in ***Chapters 2, 3, and 5*** are based on cross-sectional household survey data collected from farm households in inland valleys in Côte d'Ivoire and Ghana using the Rural Household Multiple Indicator Survey (RHoMIS) tool (van Wijk et al., 2020). The details of the methods are indicated in the respective chapters.

RHoMIS survey tool captures extensive information on household characteristics, livelihood strategies, agricultural systems, food security, crop production, wild foods, poverty, household assets, land use, and tenure variables. To capture the most important variables of interest for this study, the standard RHoMIS tool was modified with additional modules of questions and indicators. These include inland valley and rice farming practices, technology adoption, resource use and constraints, institutional and governance structures, ecosystem services, wild food use, and market variables. The amended RHoMIS questionnaires used for the household survey are provided in Appendix 1.

For ***Chapter 4*****,** I applied survey-based discrete choice experiments (DCE) modelling. The DCE allows for determining the importance of multiple attributes of a good with different levels, making trade-offs among these attributes, and assessing the likely effects of changing the value of any attribute at once (Louviere et al., 2000). The details of the methods are indicated in Chapter 4**.** The DCE questionnaires are provided in Appendix 2.

Study regions were selected in collaboration with national partners in Côte d'Ivoire and Ghana to capture variation in farming systems. A multi-stage sampling technique was used to select inland valleys and farmers in the study regions. In the first stage, inland valleys were selected based on predefined criteria to capture variation in key characteristics. In the second stage, farm households were selected randomly from these valleys. We followed the same sampling approach for the RHoMIS and DCE. Further details of the sampling approach are provided in each chapter.

1.7.1 Methodological approach per research question

To answer the first research question, we assessed in ***Chapter 2*** the diversity of farm types, food security, and the relevance of ecosystem services to smallholder farmers. Specifically, a farm typology approach was used to identify the farm types. Then we characterised the inland valley farming systems based on household demographic, agricultural, and institutional indicators, and the relevance of ecosystem services across study regions and farm types.

To address the second research question in ***Chapter 3***, I assessed the factors influencing farmers' decisions to adopt inland valley farming and rice production in order. I used an econometric modelling approach. The econometric analysis enables the identification of the key socio-economic, institutional, and physical capital factors influencing farmers' decisions to adopt inland valley farming and rice production.

Chapter 4 explores smallholder farmers' preferences for alternative land use and development options and seeks to understand how these preferences can be attributed to farm and farmer characteristics. A DCE was applied, in which alternative land use options were described by combinations of attributes and levels, and choice sets were constructed and presented to respondents. The DCE method enables the assessment of trade-offs between different land use attributes and the analysis of farmers' preferences. I used an econometric modelling approach to identify factors that drive potential heterogeneity in farmer preferences.

To answer the fourth research question, ***Chapter 5*** examines the contribution and monetary quantification of wild foods sold and consumed to household food security (kcal) and poverty (via income). Food security was assessed using the food availability indicator, which estimates the potential annual energy available at the household level (Frelat et al., 2016; Hammond et al., 2017). This energy for the food availability was

calculated from on-farm crop consumed, purchased foods (income from on-farm and off-farm activities), and wild foods consumed and sold, following established procedures in the literature (e.g., Frelat et al., 2016), expressed in kilocalories per MAE^{-1} day^{-1}.

To quantify the contribution of wild foods to food security in monetary terms, the dietary energy (kcal MAE^{-1} day^{-1}) obtained from the total wild food harvest was monetised using a replacement cost method, where we computed the cost of purchasing an equivalent amount of dietary energy from the local staple, maize. In addition, an econometric modelling approach was used to identify the factors influencing wild food collection. Moreover, I assessed the link between the perceived importance of provisioning ecosystem services (PES) and wild food collection using correlation analysis.

1.8 Outline of the thesis

The thesis comprises six chapters, including the introductory chapter ***(Chapter 1)***. ***Chapter 2*** provides an in-depth analysis of farming systems in inland valleys and assesses farmers' food security and awareness of ecosystem services in Côte d'Ivoire and Ghana. ***Chapter 3*** examines the main determinants of farmers' decisions to adopt inland valley farming and rice production practices in Côte d'Ivoire and Ghana. ***Chapter 4*** explores farmers' preferences for land use and development options in the inland valleys of Côte d'Ivoire and Ghana. In addition, I examine and identify the heterogeneity in preferences attributed to socio-economic, farm, and institutional characteristics. ***Chapter 5*** analyses the contribution of wild food collected from inland valleys to smallholder farm households' food security. In addition, I identify the major determinants that influence farm households' wild food collection in the inland valleys and assess the link between the perceived importance of provisioning ecosystem services (P-ES) and wild food collection. ***Chapter 6*** provides a synthesis of the main findings of the thesis, addresses the study limitations, and discusses the implications of the findings for policy and future research.

Chapter 2

Farming Systems, Food Security and Farmers' Awareness of Ecosystem Services in Inland Valleys: A Study from Côte d'Ivoire and Ghana

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Abstract

Inland valleys in West African countries have increasingly been used for crop production, including rice cultivation. Though it is widely assumed that inland valleys have a high potential to contribute to food security of West African countries, a comprehensive assessment of farming systems addressing agricultural, institutional, food security, poverty, and ecosystem indicators is still lacking. This study characterises inland valleys' smallholder farm households at the regional and farm type level using Rural Household Multiple Indicator Survey (RHoMIS) data collected from 733 randomly selected farm households in four agro-ecological regions, i.e., Bouaké and Gagnoa in Côte d'Ivoire, and Ahafo Ano North and Ahafo Ano South in Ghana. A farm typology is developed, and farm households are characterised with regard to demographic, agricultural, economic, and institutional indicators. Furthermore, farm households' food security and poverty status, and the importance of rice in the portfolio of crops, is assessed. Finally, farmers' awareness of different ecosystem services for their food security is examined. Four farm types are identified, i.e., farmers who rent all the land cultivated, farmers who own some land and rent extra land, farmers who own and cultivate all their land, and farmers cultivating only a part of the land they own. We find that the variation in farm households' demographic, economic, and institutional characteristics is greater between regions than within regions. Crop production, either for direct consumption or marketing, especially rice production, is the main contributor to daily energy intake, followed by wild food consumed. Still, a substantial percentage of the farm households (16-38%) in all regions cannot meet minimum daily energy requirements. Farmers of all farm types, and in all regions, attach high relevance to inland valleys' provisioning ecosystem services, particularly the ability to provide food. A majority of farmers in all regions highlighted the relevance of regulating ecosystem services, including climate regulation, water storage, and groundwater values for their well-being. In contrast, farmers attached relatively lower relevance to cultural ecosystem services. Interventions to improve national rice production need to acknowledge and preserve the diversity ecosystem services that inland valleys provide to smallholder farm households.

Keywords: Ecosystem services, farm types, farming system, inland valleys, rice cultivation, West Africa, food security.

2.1 Introduction

Smallholder-based farming is a major source of livelihood for the rural population in West Africa. Farm households in this region derive their food and income mainly through crop production, livestock rearing (Thornton et al., 2010; Kuivanen et al., 2016), and fish farming (Kiepe, 2006; Sanni, 2006). Notwithstanding, in most West African countries, food and nutrition insecurity has remained a severe problem (FAO, 2017), with a high prevalence in rural areas (Livingston et al., 2011). Inland Valleys, being seasonally flooded wetlands, including hydromorphic fringes and valley bottoms (Rodenburg et al., 2014), have increasingly been used for crop production, in particular for rice. Still, there is little insight into the structure of farming systems at the regional level, which is a prerequisite for informed decision-making on the use of inland valleys for food production.

Though rice makes an important contribution to peoples' diets, self-sufficiency in rice production in West African countries is not yet achieved (van Oort et al., 2015; Fontan Sers and Mughal, 2020; Soullier et al., 2020). On the contrary, West African countries import rice from the international market to bridge the gap between domestic rice demand and supply (Mendez del Villar and Lançon, 2015). In recent years, several West African countries have started National Rice Development Strategies (NRDS) to intensify inland valley rice production (Soullier et al., 2020). Yet farmers' rice yields are on average less than 2 t/ha - far below the rainfed lowland rice production potential yield of 6.5 t/ha (Saito et al., 2015; Niang et al., 2017).

Besides being used for food production, inland valleys provide diverse market and non-market goods and services called ecosystem services (ES), from which local communities derive various benefits. Following the Millennium Ecosystem Assessment (MEA, 2005), ES can generally be categorised into four types: provisioning, regulating, cultural, and supporting ES. Food production can be characterised as a provisioning ES offered by inland valleys. Intensifying food production in inland valleys can improve smallholder farmers' food security in West African countries. Until now, however, inland valley farm households' awareness of ES, and the relevance they assign to ES for sustaining their livelihoods, are poorly understood. Unravelling farmers' perception of the relevance of ES can be a useful entry point for future development of the region and ensure that policy efforts for inland valley cultivation are accepted by inland valley users. Furthermore, food production must be balanced with the maintenance of ecosystem services to ensure the

long-term sustainability of inland valley resource use. Establishing sustainable food production systems in inland valleys requires, therefore, an understanding of how ES contributes to farmers' well-being and if and how food production can be combined with other ES. This requires a comprehensive characterisation of farming systems in and around inland valleys.

Though several studies have analysed options for sustainably intensifying food production in inland valleys (e.g., Schmitter et al., 2015; Dossou-Yovo et al., 2017), an in-depth assessment of farming systems in terms of the agricultural and institutional indicators is still inadequate. Besides, farm households' food security status and smallholder farmers' perceptions of the relevance of ES provided by inland valleys have not been investigated yet.

The aim of this paper is to characterise inland valley's farming systems in West Africa according to household demographic, agricultural, economic, and institutional indicators and assess the relevance of ecosystem services for farmers. We use an extended version of the Rural Household Multiple Indicator Survey tool (RHoMIS), which has been widely applied and verified in Sub-Saharan Africa (Frelat et al., 2016; Hammond et al., 2017; Wichern et al., 2018) and Asian countries (e.g., India) (Lopez-Ridaura et al., 2018). Specific attention is given to the importance of rice cultivation in the portfolio of crops, given the local and national importance as a food crop. This allows us to develop a farm typology for the selected countries and regions and to systematically characterise farm households in inland valleys in West Africa. Farm households in rural West Africa are highly diverse regarding resource endowments and demography (e.g., Falconnier et al., 2015; Kuivanen et al., 2016). Moreover, biophysical conditions, such as rainfall, temperature, and soil types, differ among regions (Iizumi and Ramankutty, 2015), affecting farm households' agricultural productivity (Falconnier et al., 2015; Kuivanen et al., 2016). Next, we analyse household food security, the poverty status, and the relative importance that farm households attach to different ES across farm types and regions. This will facilitate the development of developing sustainable food production systems in inland valleys and design interventions that provide a wide range of options suitable for different farm households as mentioned by (Castro et al., 2011; Shoyama et al., 2013; Douxchamps et al., 2015; Hammond et al., 2017; Lopez-Ridaura et al., 2018).

2.2 Material and methods

2.2.1 Selection of study regions and inland valleys

Data collection was conducted in four regions, two in Côte d'Ivoire (Bouaké and Gagnoa regions) and two in Ghana (Ahafo Ano North and Ahafo Ano South regions) (Figure 2.1). These regions are major rice-growing areas that differ for their agricultural potential due to their different biophysical and socio-economic characteristics (Table 2.1). 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.

A database of all inland valleys in the selected regions, including the geo-referenced position, was provided by national research institutions, the National Centre for Agricultural Research/ (CNRA), and the National Agency for Rural Development (ANADER) in Côte d'Ivoire and the Council for Scientific and Industrial Research – Soil Research Institute (CSIR-SRI) in Ghana. Four selection criteria were identified based on scientific literature, information from partners, and transect walks in three inland valleys in Gagnoa (Table 2.2). We used a simple multi-criteria analysis (MCA) by assigning scores from 1-3 to each of the four selection criteria characterising inland valleys together with members of the national partner institutions, where 1 indicates a low and 3 a high relevance. The scores were summed to 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 (Figure 2.1), out of 46 inland valleys in Gagnoa, 29 inland valleys in Bouaké, 40 inland valleys in Ahafo Ano North, and 17 inland valleys in Ahafo Ano South.

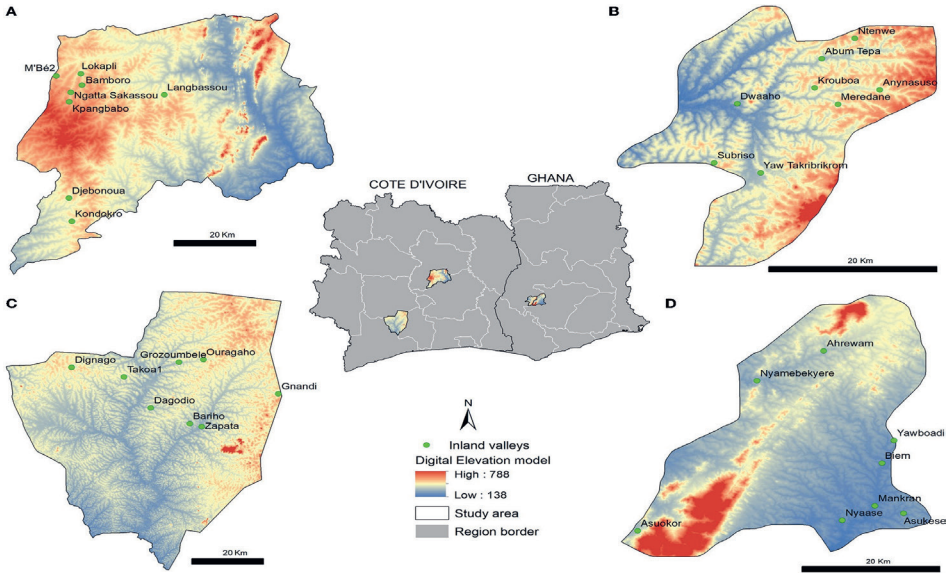


Figure 2.1: Map of the study area with the four regions and eight inland valleys selected in each region (A) Bouaké [top left], (B) Ahafo Ano North [Top right], (C) Gagnoa [bottom left], and (D) Ahafo Ano South [bottom right].

Table 2.1: Main characteristics of the selected regions in Côte d'Ivoire and Ghana (2018-19)

	Côte d'Ivoire		Ghana	
Characteristics	Bouaké	Gagnoa	Ahafo-Ano North	Ahafo-Ano South
Agro-ecological zone (AEZ)	Transitional Savannah zone	Humid dense forest of south	Transitional zone	Semi-deciduous forest
Geo-location	Lat 7° 57' N and 7° 38' N Long 4° 44' W and 5° 0' W	Lat 6° 6' N and 5° 49' N Long 5° 49' N and 6° 11' N	Lat 6°47'N and 7^0 02'N Long 2° 26'W and 2^0 04'W	Lat 6° 55' N and 7^0 10'N Long 1° 57' W and 2°20'W
Mean annual temperature (°C)	24	29	28	30
Mean annual rainfall (mm)	1525 (unimodal)	1950 (bimodal)	1300 (unimodal)	1500 (bimodal)
Dominant soil type (FAO)	Ferrasols	Acrisols	Plinthic Luvisols	Ferric luvisols
Population density (km^{-2})	201	130	196	122
Major agricultural economic activities	Food crops, livestock, fisheries, cash crops, and off-farm	Food crops, livestock, fisheries, cash crops, and off-farm	Food crops, Forestry, Fisheries, Livestock	Food crops, Livestock, Fish farming, agro-forestry

Source: Ghana Statistical Services (2014), National Institute Statistics (2014) and Kone et al. (2017).

Table 2.2: Criteria to select inland valleys in Côte d'Ivoire and Ghana

No	Criteria	Score	Explanation
1.	Physical accessibility	[1] Limited (by foot only) [2] Medium (by bicycle or motorbike) [3] Good (by car)	Better accessibility gives a larger potential for development
2.	Level of development interventions	[1] High [2] Medium [3] No intervention	Interventions reduce the representativeness of inland valleys for analysing the impact of this research
3.	Crop diversity	[1] One crop per year [2] Two crops per year [3] More than two crops per year	The objective of the CIPA[1] project is to achieve food and nutrition security
4.	Type of water management	[1] Managed by public or private agencies [2] Co-managed by farmers and public or private agency [3] Managed by farmers only	Water management by farmers enhances ownership of the infrastructures (irrigation and drainage canals), which increases incentives to properly manage water resources.

CIPA refers to "Capitalising the inland valley potential for food and nutrition security for smallholder farmers in West Africa."

2.2.2 Household surveys

From July to August 2018, a socio-economic and agronomic household survey was conducted in the 32 selected inland valleys of Côte d'Ivoire and Ghana using the Rural Household Multiple Indicator Survey (RHoMIS). Farm households were selected randomly, keeping the sample size per inland valley proportional to the size of the population. In line with the household survey ethics, farm households were offered the option of written informed consent to participate or not. In total, 733 smallholder farmers (361 in Côte d'Ivoire and 372 in Ghana) were interviewed. RHoMIS supports data storage and analysis (van Wijk et al., 2020) and reports with focus indicators are automatically generated (Hammond et al., 2017). This enables an effective and transparent assessment of farm performance and comparison of household data across countries and regions. We extended RHoMIS with questions based on our specific research goals related to farming practices, rice production, institutional and governance structures, farmers' awareness of ecosystem services, and market variables. The selection of variables was based on the findings of previous studies, which showed that site and household-specific variables such as household resource endowment, land tenure, market, institutional, agricultural, and economic conditions directly influence the opportunities and the constraints for farm household development (e.g., Righi et al.,

2011; Mutoko et al., 2014; Kamau et al., 2018; Lacoste et al., 2018). Additionally, an in-depth analysis of agricultural and institutional indicators facilitates a better understanding of the current farming practices and of the diversity of livelihood activities. The questionnaire was pre-tested, adapted, and implemented using the Open Data Kit (ODK) data collection tool and installed on Android-based tablets. Enumerators were trained, and the data were collected using face-to-face interviews.

2.2.3 Development of a farm typology

We constructed a farm typology based on the survey data using a principal component analysis (PCA) and expert knowledge from researchers, extension agents, and farmers. First, the PCA was used to reduce the dataset to the non-correlated indicators and to gain insight into the major sources of variability among households. Secondly, the local experts contributed to the selection of key indicators, which served as discriminating criteria for developing the farm typology for the selected regions. The typology was discussed with farmers, and they acknowledged it. Household income was converted into USD using the purchasing power parity (PPP) conversion factor in the year of study, based on the world development indicator to facilitate country-wise comparison (World Bank, 2020b). Household cash income was calculated based on the income received by farm households in the form of cash from the sale of farm produce food crops, livestock sold, wild foods collected and sold, and off-farm activities as reported by farmers.

2.2.4 Assessment of food and nutrition security and poverty

The 'potential food availability (FA)-energy' and the household dietary diversity score (HDDS) were used as proxies to assess farm households' food and nutrition security, respectively. Both have been widely used to assess food availability and nutritional quality of household's diets in different studies in Sub-Saharan Africa (Ritzema et al., 2017; Wichern et al., 2018) and Asia (e.g., India) (Lopez-Ridaura et al., 2018). The PFA, expressed in kcal per male adult equivalent (MAE) per day (MAE^{-1} $d^{-1)}$, is a supply-based estimate of the potential amount of food generated through on- and off-farm activities (Frelat et al., 2016; Hammond et al., 2017; Ritzema et al., 2017) and is provided by the RHoMIS tool. Farm households with less than 2500 kcal MAE^{-1} d^{-1} are considered food insecure (UNU and WHO, 2004; Smith and Subandoro, 2007). The HDDS was computed from the frequency of food groups consumption during a 4-week recall period (Hammond

et al., 2017; van Wijk et al., 2020). According to FAO (2006), HDDS scored ≤ 3 as low dietary diversity, 4-5 as a medium, and ≥ 6 as high. The poverty level was assessed using the World Bank international poverty line of US$ 1.90 per person per day. According to the World Bank (2020a), extreme poverty is measured as the number of people living on less than US$ 1.90 per day (in 2011, international PPP).

2.2.5 Assessment of ecosystem services

To identify ES categories to be used in the survey, we adopted a four-step approach. First, we defined four ES categories: provisioning, regulating, supporting, and cultural services. Second, a list of 21 ES (7 provisioning ES, 7 regulating, 1 supporting and 6 cultural ES) provided by inland valleys was constructed based on the scientific literature on ecosystem service valuation, focusing on wetlands (MEA, 2005; Wangai et al., 2016; Costanza et al., 2017) (Table A.1). Thirdly, the survey was tested with 25 inland valleys farm households in the Bouaké region. Using farmers' feedback, the rather academic terms for different ES were translated into formulations that farm households can better understand. Fourth, we allowed farmers to add ES not included in our list. The respondents scored the ES on a Likert scale of 1-5 (1 = not at all important to 5 = very important). The scores allowed analyzing the perceived importance of ES between regions and farm types within regions.

2.2.6 Statistical analysis

Descriptive statistics were employed to analyse the indicators of farm households per region and farm types. Data were analysed using Stata SE 16 (StataCorp, 2017) and R 3.6.1 (R Core Team, 2018). Quantitative variables between regions and farm types were compared using a one-way analysis of variance (ANOVA). The median and interquartile values were reported where the variable was not normally distributed. The (non-parametric) Kruskal-Wallis *H* one-way analysis of variance was employed to compare the median significance difference between regions or farm types. To analyse differences between regions or farm types within a region, mean values were tested for significance using the posthoc Bonferroni correction test at $P < 0.05$. The posthoc Dunn test with Bonferroni adjusted test at $P < 0.05$ was used for the median. Finally, Kendall's W test was used to rank the crops that farmers perceived important among the portfolio of crops cultivated in inland valleys of each region. The importance of cultivated crops as perceived by the respondents was rated using a Likert scale of 1-5 (1 = not at all important

to 5 = very important). The reliability, internal consistency, and sample adequacy of the Likert scale values for ES farm households' awareness were tested with a Cronbach's alpha test. Besides, the relationship between the ES categories were assessed using Spearman's correlation coefficients.

2.3 Results

2.3.1 Comparison of farm households' characteristics across regions

Table 2.3 shows the farm households' basic characteristics in the four regions in Côte d'Ivoire and Ghana, organised according to demographic, agricultural, economic, and institutional indicators.

2.3.1.1*Household demography*

Farm household demographic indicators varied between regions within each country. Farm household heads in all regions were predominantly male and significantly more so in Côte d'Ivoire than in the Ghanaian regions. The education level was significantly higher in Ghana than in Côte d'Ivoire. Family size was larger in Côte d'Ivoire, and it was significantly larger in Bouaké than in Gagnoa.

2.3.1.2*Agricultural production systems*

The agricultural production systems differed significantly ($P < 0.001$) among regions in terms of land owned, land cultivated, crop intensity, presence of perennial crops, rice cultivation, and use of inland valley bottom (Table 2.3, B). The area of land owned in Bouaké (5.9 ha) was significantly larger than in Gagnoa (3.6 ha), which was again significantly larger than in Ahafo Ano North and Ahafo Ano South (both 1.7 ha). In contrast, the cultivated land area in Gagnoa (3.7 ha) was significantly larger compared with that in the three other regions. On average, farm households cultivated two to three crops per year in each region. The share of farm households owning perennial crops was largest in Gagnoa (60%), followed by Bouaké (46%) and then both Ghanaian regions (34 and 35%). Regions differed significantly in the share of farmers growing rice in the order with Gagnoa the most (86%), then Ahafo Ano South, Bouaké, and Ahafo Ano North the least (45%). The highest share of inland valley bottom users was in Gagnoa and Ahafo Ano North, while the smallest share was in Bouaké and Ahafo Ano South. The share of farmers cultivating rice is smaller than the share of farmers using the valley bottoms in all regions, except Gagnoa, where it is similar.

2.3.1.3*Socio-economic characteristics*

Farming was the main source of income for all households. None of the economic indicators related to household income differed significantly between regions due to the large observed variation within each region. There is a slight difference between households' farm income and total income. The difference between both incomes varies from 87 USD year^{-1} (Bouaké) to 805 USD year^{-1} (Ahafo Ano South). Activities such as livestock and hiring out labour were marginal contributions to household income. However, the proportion of households hiring labour varied significantly ($P < 0.001$) between regions and was significantly higher in Bouaké and Ahafo Ano North than in the other regions.

2.3.1.4*Institutional services*

All institutional service indicators varied significantly ($P<0.001$) across regions (Table 2.3, D). The share of farm households with access to extension services was higher in both Ghanaian regions (50%) than in Côte d'Ivoire (29%). In contrast, a relatively large share of farmers had access to credit in Bouaké and Gagnoa compared with Ahafo Ano North and Ahafo Ano South. A relatively large share of households had access to a market in Bouaké and Ahafo Ano North compared with the other regions.

2.3.1.5*Main crops cultivated in the study regions*

Most farm households cultivated between two and three crops per year. The importance of crops related to their economic value and home consumption, indicated on a scale from 0 to 12, varied between regions (Table A.2). The variation of cultivated crops may be explained by the regions' biophysical conditions, the diet habits of households, and market demand in each region. Rice, both a food and a cash crop, scored highest in all regions, followed by cocoa, a perennial cash crop in Gagnoa and Ahafo Ano North. In contrast, a food crop, yam and maize were ranked as second crops respectively in Bouaké and Ahafo Ano South. The third crop is a perennial cash crop in all regions except Ahafo Ano North, where maize has a third place.

2.3.2 Comparison of farm household characteristics across farm types

2.3.2.1 *Farm typology*

KMO test on indicators of surveyed farmers was significant (P > 0.001) and its value in each region was greater than 0.5 (Table 2.4), which is appropriate to proceed to factor analysis. The PCA identified the indicators with the highest loading Eigenvalues, which were: 'cultivated land,' 'land owned,' 'household size,' 'cultivated land: household size ratio,' and 'land owned: household size in MAE ratio' (Figure A.1). In consultation with local experts, we classified households into farm types by land tenure (owned or rented) and land use (cultivated or not cultivated by the owner). Four farm types (FT) were identified: FT1 farmers who rent all the land they cultivate (most of them, but not all, being immigrants), FT2 farmers own some land and rent extra land (rent-in land), FT3 farmers own and cultivate all their land; FT4 farmers cultivate only parts of the land they own (Figure 2.2).

Table 2.3: Farm household characteristics in the four study regions based on the household baseline survey 2018-2019; (proportion or means ± standard deviation).

Indicators	Unit	Côte d'Ivoire		Ghana		*P*-value
		Bouaké (n=226)	Gagnoa (n=135)	Ahafo Ano North (n=184)	Ahafo Ano South (n= 188)	
A. Demographic indicators						
Age of HHs	Years	44.8±14.7^{a}	47.1±12.5^{a}	43.7±12.1^{a}	44.8±12.0^{a}	ns
Gender (1=male)[1]	%HHs	90^{ab}	96^{a}	76^{c}	83^{bc}	< 0.001
Education	Years	3.3±4.1^{b}	3.7±4.1^{b}	7.4±5.7^{a}	6.1±4.9^{a}	< 0.001
Family size	Number	7.6±3.5^{a}	6.6±3.1^{b}	5.5±2.3^{bc}	6.1±2.5^{c}	< 0.001
B. Agricultural indicators						
Land owned	Ha	5.9±6.6^{a}	3.6±4.3^{b}	1.7±3.5^{c}	1.7±4.9^{c}	< 0.001
Land cultivated	Ha	2.7±3.8^{b}	3.7±3.3^{a}	2.1±3.1^{b}	2.9±2.9^{ab}	< 0.001
Crop diversity	Number	2.3±0.7^{a}	2.2±0.6^{a}	2.1±0.4^{b}	2.0±0.3^{b}	< 0.001
Owner of perennial crop (1=yes)[1]	%HHs	46^{b}	60^{a}	34^{c}	35^{c}	< 0.001
Farmers growing rice (1=yes)[1]	%HHs	59^{c}	86^{a}	45^{d}	63^{b}	< 0.001
Use of inland valley bottom (1=yes)[1]	%HHs	68^{b}	85^{a}	80^{ab}	75^{b}	< 0.05
Livestock holding[2]	TLU	0.3±1.0^{a}	0.8±4.9^{a}	0.6±1.3^{a}	0.7±1.8^{a}	ns
C. Socio-economic indicators						
Farm income[3]	USD year^{-1}	2039 (5032) ^{a}	3253.0 (23899) ^{a}	2983.0 (6891) ^{a}	3675.0 (16582) ^{a}	ns
Total income[3]	USD year^{-1}	2126.0 (8841.0)^{a}	3721.0 (23647) ^{a}	3187.0 (6846.0) ^{a}	4480.0 (21907) ^{a}	ns
Household hiring labour (1=yes)[1]	%HHs	65^{a}	48^{b}	69^{a}	50^{b}	< 0.001
D. Institutional service indicators						
Access to extension services (1=Yes)[1]	%HHs	20^{c}	29^{b}	50^{a}	48^{a}	< 0.001
Access to credit (1=Yes)[1]	%HHs	47^{a}	35^{b}	13^{c}	2^{d}	< 0.001
Access to market (1=Yes)[1]	%HHs	82^{a}	50^{c}	80^{a}	70^{b}	< 0.001

a-d: Mean values followed by different letters in rows are different at Bonferroni-adjusted significant level $P \leq 0.05$ (posthoc tests with Bonferroni correction for multiple comparisons). **1:** The percentage share of households (%HHs**)** in a yes/no scale responding farm households who answered yes. **2:** The tropical livestock unit (TLU) combined numbers across species into a single figure. **3:** Median and interquartile value in brackets of total income and farm income variables.

Table 2.4: Result of the KMO test

Region	KMO	*P*-value
Gagnoa	0.544	0.000
Bouake	0.505	0.000
Ahafo_Ano_North	0.552	0.000
Ahafo_Ano_South	0.516	0.000

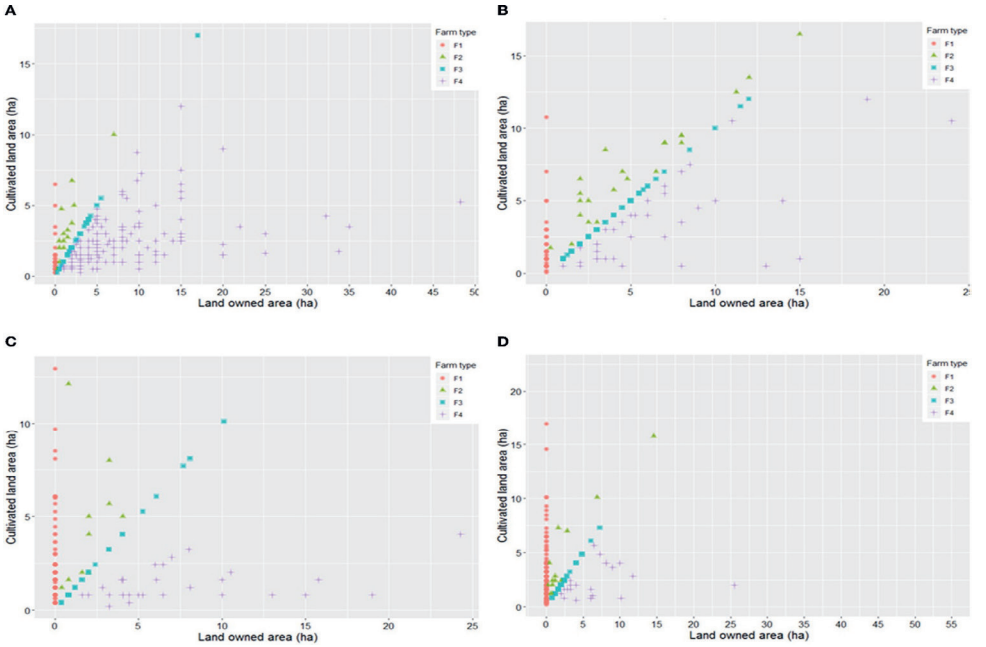


Figure 2.2: Cultivated area against land owned for all farm households in (A) Bouaké [top left], (B) Gagnoa [top right], (C) Ahafo Ano North [bottom left], and (D) Ahafo Ano South [bottom right].

2.3.2.2 *Differences between farm types across regions*

Tables 2.5 and 2.6 summarise key indicators of the four farm types across the four regions. They show that there are no consistent significant differences between farm types over all regions. Each region has its own specific characteristics. The farm household head's education level differed in all regions except Bouaké. The crop diversity of farm types within each region was similar, except for Bouaké. In Gagnoa and Ahafo Ano South, more farmers in FT2 and FT4 cultivated perennials, and in Ahafo Ano South also FT3. The share of farm households growing rice did not differ among farm types, except for Ahafo Ano South, where the farm types with a high score on perennials scored lower on rice cultivation. Access to credit only differed between farm types in Gagnoa, while in Ahafo Ano North, access to extension service varied.

In Bouaké, 66% of the farmers cultivated less land than they own (FT4). Famers renting extra land (FT2) constituted only 6% of the sample. The farmers renting all their land (FT1) and the large farmers cultivating only part of their land (FT4) had a larger income than FT2 and FT3 farmers. Besides, a larger number of farmers belonging to FT1 and FT4 were hired as labour. Of the farmers renting extra land, 80% depended on farming, while this percentage was 95% or more for farmers of the other farm types. Although the difference was not significant, fewer farmers renting all their land tended to cultivate rice, use land in the valley bottom, and use extension services despite their higher income.In Gagnoa, the farmers are distributed more or less evenly across farm types, although the farmers renting extra land (FT2) comprised only 13% of the surveyed farmers. The farmers cultivating only part of their land (FT4) were better educated. Similar to Bouaké, farmers renting extra land (FT2) depended on farming for 80% of their income. For the other farm types, this was above 90%, on average, but none depended solely on farming. Only a small share of FT1 had perennial crops because this group of farmers has a land-sharing contract with perennial tree crop owners. In contrast to Bouaké, more of them tended to cultivate rice and used land in the valley bottom, although it was also not significant. More farmers renting all their land (FT1) and farmers renting-in extra land (FT2) had to access credit.

In Ahafo Ano North, 65% of the surveyed farmers rented all their land (FT1), and farmers renting extra land (FT2) were only 5%. The FT1 farmers were younger than the others, although not significantly different from the farmers renting-in extra land (FT2).

The number of years of education of the FT1 farmers was smaller than for the other farmers. A smaller share of the FT4 farmers used to cultivate the valley bottom, and fewer tended to grow rice. Farmers of all farm types depended 95% or more on farming for their income. In Ahafo Ano South, 62% of the farmers surveyed rented all their land (FT1), and 7% rented extra land (FT2). A larger part of the FT1farmers and the farmers cultivating only part of their land (FT4) was male than in farm types 2 and 3. The number of years of education of farmers renting all their land (FT1) and farmers renting extra land (FT2) was less than for farmers cultivating all their land (FT3) and those cultivating part of their land (FT4). Those farmers (FT1 and FT2) cultivated more rice than FT3 and FT4. The farmers renting extra land (FT2) owned substantially more livestock than the other farmers. These are also farmers that entirely depend on agriculture for their living. The other farm types are less dependent on farming, with FT4 the least, for 70%. In all regions except Bouaké, a large percentage of the FT4 farmers cultivated perennial crops, which is one of the upland crops, and specifically in Ghana, FT4 farmers cultivated less on inland valley bottomlands. Farmers with limited land ownership(FT1, FT2) tended to a large extent to cultivate the inland valley bottom; overall, more than 75% of them.

Table 2.5: Farm household indicators (proportion and means ± standard of deviation) for the four farm types in selected regions of Côte d'Ivoire, based on the RHoMIS household baseline survey (2018-2019).

Indicators	Côte d'Ivoire									
	Bouaké					Gagnoa				
	FT1 (n=25)	FT2 (n=14)	FT3 (n=38)	FT4 (n=149)	P-value	FT1 (n=38)	FT2 (n=18)	FT3 (n=43)	FT4 (n=36)	P-value
Share of samples (%)	11	6	17	66		28	13	32	27	
(A) Classification criteria										
Land owned* (ha)	0[c]	1.4 ± 1.7[b]	2.7 ± 2.7[b]	8.1 ± 7.0[a]	<0.001	0[c]	4.4 ± 3.8[ab]	3.8 ± 2.6[b]	6.9 ± 5.3[a]	<0.001
Land cultivated* (ha)	4.0± 10[a]	3.5 ± 2.4[a]	2.7 ± 2.7[a]	2.5 ± 1.8[a]	ns	2.4 ± 3.5[b]	7.0 ± 3.1[a]	3.8 ±2.6[b]	3.4 ± 3.0[b]	<0.001
(B) Demographic indicators										
Age of HH head (years)	40.1 ± 12.5[a]	46.8 ± 20.2[a]	43.6 ± 14.0[a]	45.6 ± 14.7[a]	ns	44.7 ± 12.6[a]	43.9 ± 11.2[a]	47.7 ± 12.7[a]	50.6 ± 12.2[a]	ns
Gender (1=male)[1]	92[a]	100[a]	89[a]	89[a]	ns	94[a]	100[a]	95[a]	97[a]	ns
Education (Years)	4.4 ± 4.6[a]	2.6 ± 3.8[a]	2.5 ± 43.3[a]	3.4 ± 4.3[a]	ns	2.0 ± 3.0[b]	3.4 ± 4.0[b]	2.9 ± 4.2[b]	6.4 ± 3.9[a]	<0.001
Family size (person)	6.5 ± 2.4[a]	9.4 ± 3.6[a]	7.6± 3.7[a]	7.6 ± 3.6[a]	ns	6.4 ± 3.4[a]	7.5 ± 2.0[a]	6.8 ±3.3[a]	6.2 ± 2.9[a]	ns
(C)Agricultural indicators										
Crop diversity (number)	2.3 ± 0.9[ab]	2.7 ± 0.9[a]	2.1 ± 0.5[b]	2.3 ± 0.6[ab]	<0.001	2.3 ± 0.8[a]	2.0 ± 0.2[a]	2.1 ± 0.5[a]	2.3 ± 0.7[a]	ns
Owner of perennial crop (1=yes)[1]	32[a]	42[a]	42[a]	49[a]	ns	13[b]	77[a]	76[a]	80[a]	<0.001
Farmers growing rice (1=yes) [1]	40[a]	57[a]	60[a]	63[a]	ns	94[a]	77[a]	86[a]	83[a]	ns
Use of inland valley bottom (1=yes) [1]	56[a]	78[a]	65[a]	70[a]	ns	92[a]	77[a]	83[a]	83[a]	ns
Livestock holding (TLU)	0.0[a]	0.1 ± 0.2[a]	0.3 ± 0.6[a]	0.3 ± 1.2[a]	ns	0.7 ± 2.7[a]	0.4 ± 0.7[a]	1.6 ± 8.2[b]	0.1 ± 0.4[c]	ns
(D) Economic indicators										
Farm income[2](USD year^{-1})	1913 (13416)[a]	1231 (3008)[b]	1293 (2554)[b]	2551 (16448)[a]	<0.001	1552 (19144)	4412 (11265)	2976 (48532)	4539 (21211)	ns
Total income[2] (USD year^{-1})	1913 (13282)[a]	1520 (5735)[a]	1293 (2639)[a]	2674 (28111)[a]	ns	1677 (26463)[a]	5517 (11265)[a]	3122 (48532)[a]	4986 (21211)[a]	ns
Share of farm income in total income (%)	100[a]	81[a]	100[a]	95[a]	ns	93[a]	80[a]	95[a]	91[a]	ns
Household hiring labour (1=yes)[2]	76[a]	50[b]	36[c]	71[a]	<0.001	42[a]	61[a]	39[a]	58[a]	ns
(E) Institutional service indicators										
Access to market (1=yes)[1]	96[a]	71[a]	75[a]	84[a]	ns	52[a]	38[a]	46[a]	58[a]	ns
Access to extension services (1= yes)[1]	08[a]	21[a]	10[a]	24[a]	ns	28[a]	27[a]	21[a]	41[a]	ns
Access to credit services (1=yes)[1]	60[a]	28[a]	42[a]	48[a]	ns	47[a]	44[a]	23[b]	33[b]	<0.05

***Note*: a-c:** Mean values followed by different letters in rows are different at Bonferroni-adjusted significant level $P \leq 0.05$ (post hoc tests with Bonferroni's correction for multiple comparisons). Means and proportions values are for continuous and categorical variables, respectively. **1:** The percentage of households (%HHs**)** on a yes/no scale responding 'yes'.**2:** Median and interquartile value in brackets of total income and farm income variables. *: Discriminative variables used for farm typology.

Table 2.6: Farm household indicators (proportion and means ± standard deviation) for the four farm types in selected regions of Ghana, based on the RHoMIS household baseline survey (2018-2019).

Indicators	Ghana									
	Ahafo Ano north					Ahafo Ano south				
	FT1 (n=120)	FT2 (n=10)	FT3 (n=23)	FT4 (n=31)	P-value	FT1 (n=117)	FT2 (n=13)	FT3 (n=35)	FT4 (n=23)	P-value
Share of samples (%)	65	5	13	17		62	7	19	12	
(A) Classification criteria										
Land owned* (ha)	0.0 ^{c}	2.0 ± 1.1^{bc}	2.8 ± 2.7^{b}	7.3 ±5.2^{a}	<0.001	0.0^{c}	2.5 ± 3.9^{bc}	2.4 ± 1.5^{b}	8.7 ± 11.1^{a}	<0.001
Land cultivated* (ha)	1.9 ± 2.0^{bc}	4.6 ± 3.3^{a}	2.9 ± 2.7^{ab}	1.3 ± 0.8^{c}	<0.001	2.8 ± 2.7^{a}	4.6 ± 4.2^{a}	2.4 ± 1.5^{a}	3.1 ± 4.3^{a}	ns
(B) Demographic indicators										
Age of HHs (years)	40.8 ± 10.8^{b}	53.3 ± 9.3^{a}	44.6 ± 2.4^{ab}	51.2 ± 3.2^{a}	<0.001	44.0 ± 12.2^{a}	47.7 ± 11.1^{a}	45.5 ± 12.8^{a}	46.3 ± 10.8^{a}	ns
Gender (1=male)[1]	80^{a}	80^{a}	78^{a}	61^{a}	ns	88^{a}	76^{b}	71^{b}	82^{a}	<0.1
Education (years)	6.0 ± 5.0^{b}	9.0 ± 3.2^{ab}	10.0 ± 3.7^{a}	10.5 ± 8.2^{a}	<0.001	5.1 ± 4.7^{c}	4.5 ± 5.1^{bc}	8.0 ± 4.8^{ab}	9.2 ± 4.3^{a}	<0.001
Family size (number)	5.6 ± 2.3^{a}	5.3 ± 3.1^{a}	5.0 ± 2.2^{a}	5.4 ±2.0^{a}	ns	6.3 ± 2.6^{a}	6.0 ± 1.8^{a}	5.6 ± 2.3^{a}	5.9 ± 2.5^{a}	ns
(C) Agricultural indicators										
Crop diversity (number per year)	2.0 ± 0.4^{a}	2.1 ± 0.3^{a}	2.0 ± 0.0^{a}	2.1 ± 0.4^{a}	ns	2.0 ± 0.4^{a}	2.0 ± 0.2^{a}	1.9 ± 0.1^{a}	2.1 ± 0.3^{a}	ns
Owner of perennial crop (1=yes)[1]	22^{c}	60^{a}	39^{b}	67^{a}	<0.001	32^{a}	53^{a}	28^{a}	52^{a}	ns
Farmers growing rice (1=yes)[1]	53^{a}	30^{a}	34^{a}	29^{a}	ns	71^{a}	69^{a}	47^{b}	43^{b}	<0.05
Use of inland valley bottom (1=yes)[1]	86^{a}	80^{a}	82^{a}	51^{b}	<0.05	77^{a}	84^{a}	74^{a}	56^{a}	ns
Livestock holding (TLU)	0.6 ± 1.3^{a}	0.3 ± 0.4^{a}	0.3 ± 0.6^{a}	0.8 ± 1.9^{a}	ns	0.6 ± 1.1^{b}	2.7 ± 5.7^{a}	0.4 ± 0.6^{b}	0.6 ± 0.9^{b}	<0.001
(D) Economic indicators										
Farm income[2] (USD year^{-1})	2936 (7149)^{a}	3125 (28575)^{a}	2849 (6111)^{a}	4487 (7998)^{a}	ns	3567 (19375)^{a}	4544 (13896)^{a}	2279 (10135)^{a}	7977 (24326)^{a}	ns
Total income[2] (USD year^{-1})	3098 (7149)^{a}	3258 (35857)^{a}	2849 (6192)^{a}	4487 (8241)^{a}	ns	4352 (22392)^{a}	4544 (13896)^{a}	2706 (11916)^{a}	11111 (26033)^{a}	ns
Share of farm income in total income (%)	95^{a}	96^{a}	100^{a}	100^{a}	ns	82^{a}	100^{a}	84^{a}	72^{a}	ns
Household hiring labour (1=yes)[1]	74^{a}	100^{a}	72^{a}	74^{a}	ns	53^{a}	61^{a}	37^{a}	47^{a}	ns
(E)Institutional service indicators										
Access to market (1=yes)[1]	79^{a}	90^{a}	82^{a}	77^{a}	ns	71^{a}	77^{a}	62^{a}	73^{a}	ns
Access to extension services (1= yes)[1]	52^{b}	90^{a}	39^{c}	38^{c}	<0.05	46^{a}	46^{a}	60^{a}	43^{a}	ns
Access to credit services (1=yes)[1]	11^{a}	10^{a}	13^{a}	25^{a}	ns	04^{a}	00^{a}	00^{a}	00^{a}	ns

Note: **a-c:** Mean values followed by different letters in rows are different at Bonferroni-adjusted significant level $P \leq 0.05$ (post hoc tests with Bonferroni's correction for multiple comparisons). Means and proportions values are for continuous and categorical variables, respectively. **1:** The percentage of households (%HHs**)** on a yes/no scale responding 'yes'. **2:** Median and interquartile value in brackets of total income and farm income variables. *: Discriminative variables used for farm typology.

2.3.3 Food security

2.3.3.1 *Potential food availability across regions and farm types*

Figure 2.3 illustrates the contribution of crop and livestock products, wild food consumed and sold, and off-farm income to the potential food availability (PFA) in different regions. Daily calorie consumption was below the recommended minimum level for about 32% of the households in Bouaké, 16% in Gagnoa, and 38% in both Ahafo Ano North and Ahafo Ano South. In all regions, crops (consumed and sold) were the main contributors to the PFA, followed by wild food consumed. The contribution of food crops sold to the overall daily energy supply increased with an increase in PFA. In Gagnoa, this applies only to households with the lowest PFA (Supplementary Figure 2.2). Other income sources (livestock, wild food sold, and off-farm activities) were of minor importance for satisfying farm households' food needs, but they also increased with the PFA (Supplementary Figure 2.2).

Further analysis of PFA at the farm-type level (Supplementary Figure 2.3) showed that the fraction of households being food insecure was less in FT4 (between 22 and 30%, respectively). One exception was observed for farmers in Gagnoa, where only a small proportion of farm households belonging to FT3 had an average food consumption below the recommended minimum calorie intake (4%). In contrast, farm households in FT3 appeared to be the most food insecure of all farm types in all other regions. In Ahafo Ano North, the contribution of wild food collected and sold was high for FT1 and FT4, whereas in Ahafo Ano South, it was high for FT3.

2.3.3.2 *Household dietary diversity across regions and farm types*

HDDS scores in all farm types across regions were higher in a good season than in a bad season (Supplementary Figure 2.5). The median HDDS during the good season was classified as high in all regions and farm types, except for FT2 and FT3 in Bouaké, where it was medium. It should be noted that the variability of the HDDS between households was large, irrespective of the season.

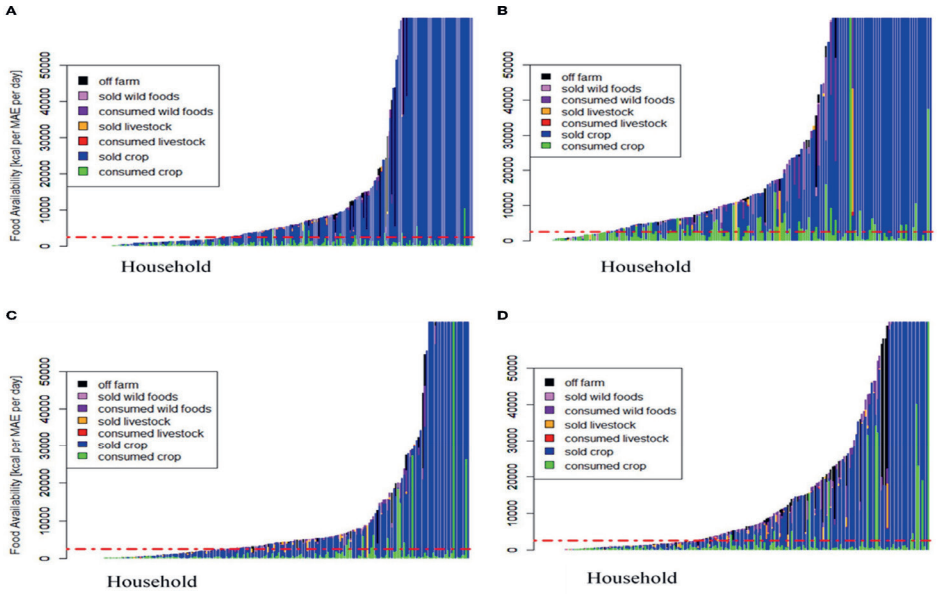


Figure 2.3: The overall distribution of food availability across all study households in (A) Bouaké [top left], (B) Gagnoa [top right], (C) Ahafo Ano North [bottom left], (D) Ahafo Ano South [bottom right]. Each vertical bar represents one household, the colours represent its energy sources, and the height represents total food availability. The red dotted line indicates the minimum energy intake of 2,500 kcal MAE^{-1} d^{-1} for food security. Thus, 32, 16, 38, and 38% of the households in Bouaké, Gagnoa, Ahafo Ano North, and Ahafo Ano South are below the minimum energy intake, respectively.

2.3.3.3 *Poverty across regions and farm types*

The actual cash income (US$ MAE^{-1} day^{-1}) for each region is shown in Figure 2.4. Between 11 and 13% of the farm households had no cash income during the 12 months prior to the survey. Moreover, 60% of households in Bouaké, 55% in Gagnoa, and 42% in Ahafo Ano North and Ahafo Ano South lived below the poverty line of US$ 1.9 MAE^{-1} day^{-1} (World Bank, 2017; World Bank, 2020a). Hence, about half of inland valley farm households fell below the poverty line in all regions. Across all regions, crop sales were the most important source of income to farm households. The poverty status and the actual cash income of farmers for each farm type per region are presented in Supplementary Figure 2.4. In general, the percentage of farm households living below the poverty line was high (> 50%) for all farm types. The contribution of wild food sold was greater for FT1 than for other farm types. The contribution of off-farm income was small.

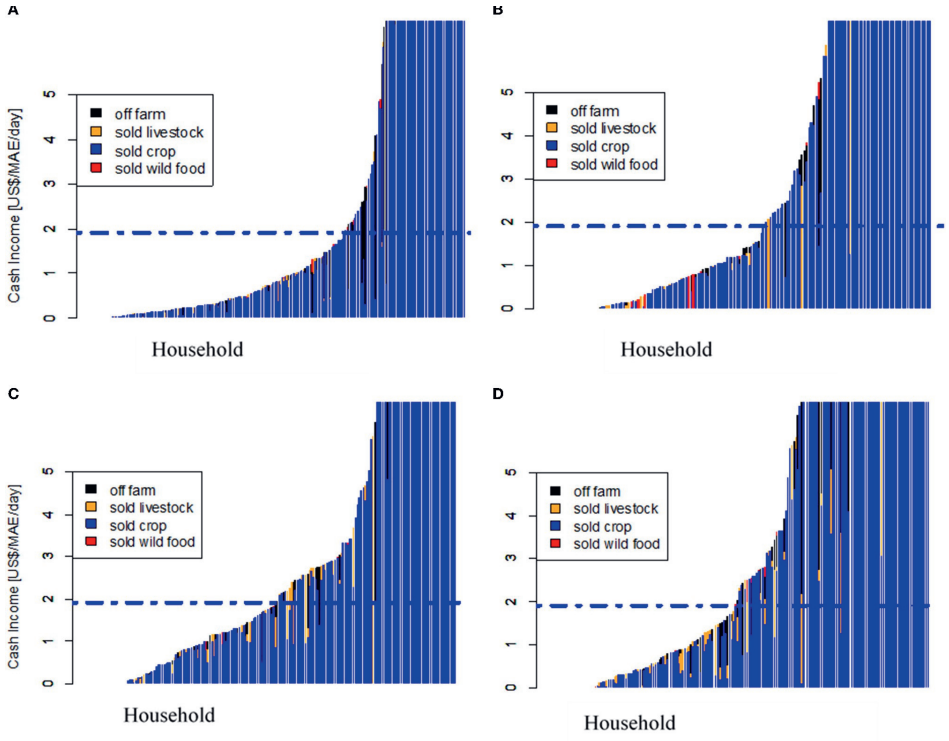


Figure 2.4: Cash income of individual farm households (A) Bouaké [top left], (B) Gagnoa [top right], (C) Ahafo Ano North [bottom left], and (D) Ahafo Ano South [bottom right]. Individual farm households are ordered on the x-axis. The blue dotted line represents the poverty line of \$1.9 day^{-1} based on the World Bank international poverty line (World Bank, 2017).

2.3.4 Farm households' awareness of ecosystem services (ES)

Overall, the pattern of awareness of farm households ES was remarkably similar within a region for the different FTs (Figure 2.5, Supplementary Table 2.3). Generally, farm households acknowledged the importance of ES for their well-being. Except for flood prevention, differences between regions for all ES scores were significant (Supplementary Table 2.3). ES scores attached to a particular category (provisioning, regulating, supporting, and cultural) differed more considerably among regions than between farm types. Farm households in all regions considered the provisioning service' food' to contribute most to their welfare.

Regarding the other provisioning ES, the differences between regions are more obvious than between farm types within each region. Whereas in Bouaké, medicinal plants, firewood charcoal, and habitat provision appeared to be moderately relevant to all

households, this was only the case for habitat provision for FT2 in Gagnoa. In contrast, farm households perceived water for domestic use more relevant in Ahafo Ano South. Households belonging to FT2 in Ahafo Ano South considered medicinal plants and habitat provision relevant, whereas these ES received low scores in Ahafo Ano North. Regarding supporting ES, soil formation is relatively important and larger in FT3 in all regions except Ahafo Ano North. In Ahafo Ano North, soil formation is higher in FT3.

Water storage, a regulating ES, seems to be important in all regions, though there were differences among FTs within regions. FT4 households assigned the highest scores to water storage in Ahafo Ano North and Ahafo Ano South, while this ES was most relevant for FT1 in Bouaké and FT2 in Gagnoa. Moreover, groundwater regulation was an important ES in all regions except Gagnoa. In Ahafo Ano North and Bouaké, FT1, FT2, and FT3 households perceived water regulation as particularly important. Bouaké was the only region where households also indicated climate regulation to be the least perceived ES. However, scores varied considerably between FTs. Finally, insect pollination received moderate scores by FTs in both regions in Ghana. However, it was considered low relevance by FTs in both regions in Côte d'Ivoire.

Regarding cultural ES, recreation was perceived as moderately relevant by all FTs in Bouaké. In contrast, the importance attached by FTs located in Gagnoa was mixed, and in Ahafo Ano North and Ahafo Ano South in Ghana, recreation did not seem to play a major role. Education is perceived structurally more relevant by farm households in Bouaké; relatively little awareness for this ES seems to exist in Gagnoa and the Ghanaian regions. Spearman's correlation coefficients regarding the relationship between the ES categories indicated a significant and strong positive correlation between provisioning and regulating ES ($r=0.57$, $P \leq 0.01$). There were also positive correlations between regulating and supporting ES ($r=0.67$, $P \leq 0.01$) and provisioning and supporting ES ($r=0.35$, $P \leq 0.01$), as well as positive correlations between provisioning and cultural ES ($r=0.54$, $P \leq 0.01$) (Supplementary Table 2.4).

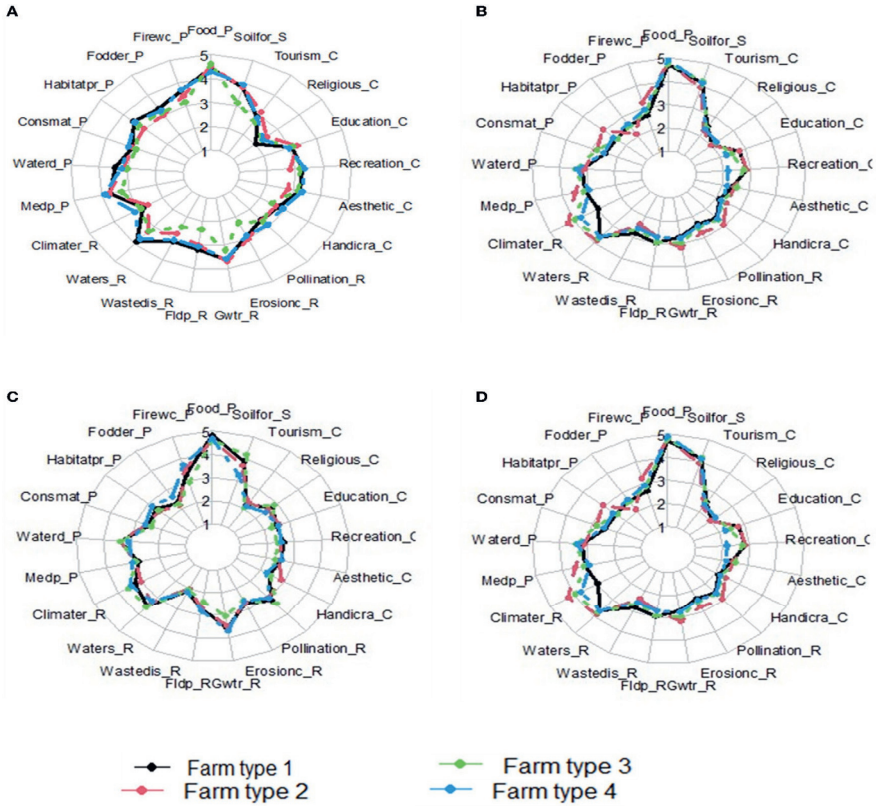


Figure 2.5: Ecosystem services at farm level in different in (A) Bouaké [top left], (B) Ahafo Ano North [bottom left], (C) Gagnoa [top right], and (D) Ahafo Ano South [bottom right]. P, R, S, and C indicate provisioning, regulating, supporting, and cultural ecosystem services, respectively. Firew_C: Firewood and Charcoal, Habitat_Pr: habitat provision, Consmat: Construction material, Medp: Medicinal plants, Waterd: Water for domestic use, Climater: Climate regulation, Waters: Water storage, Wastedis: Waste disposal, Fldp: Flood protection, Gwtr: Groundwater recharge, Erosionc: Erosion control, Pollination: Pollination insects, Soilfor: Soil formation, Handicra: Handicrafts, Aesthetic: Aesthetic values, Recreation: Recreational values, Religious: Religious values.

2.4 Discussion

2.4.1 Household diversity between and within regions

The observed variation in farm systems was larger between regions than within a region. Regions differed in terms of biophysical conditions, population density, education level, farm systems, and presence of institutional services, while within a region, these were more or less similar. A high homogeneity between the farm types within regions was also observed by (Righi et al., 2011) in Uruguay. However, in sub-Saharan Africa, other

studies found a much larger farm diversity than in our study regions (Tittonell et al., 2010; Giller et al., 2011; Mutoko et al., 2014). In those studies, wealth or resource endowment was taken as a classification criterion. We identified land tenure and cultivated area as discriminating criteria. In our study regions, a relatively large group of farmers cultivate all or parts of the land. Others own large areas but do not cultivate it all. This results in a large variation of the cultivated land area within each farm type. As an illustration, in Bouaké, the farmers renting all land cultivated a land area between 0.5 and 6 ha, and it ranged from 0.7 to 12 ha for the farmers with excess land. This is also reflected in the large variation in income within each farm type, as income, which is largely from agriculture in our study regions, is often related to the area of cultivated land.

A larger share of the households owning land, cultivated high-value perennial tree crops (i.e., cocoa and rubber) and occupied upland and inland valley bottom, while farmers who rented land mainly cultivated annual crops in the inland valley bottom. For example, in the Brong Ahafo region (Ghana), migrant farmers cultivated mainly food crops on rented land (Adjei-Nsiah et al., 2004). The share of households renting all of their land (FT1) was larger in both Ghanaian regions than in those in Côte d'Ivoire. The country-specific land tenure system might explain this. Around 80 % of the land is under customary rights in Ghana (Pande and Udry, 2005), where land belongs to the royal family and is governed by the traditional local chief. Most royal bloodline farmers have access to land by inheritance, whereas others have access to land through renting and sharecropping arrangements (Adjei-Nsiah et al., 2004; Abdulai et al., 2011). In Côte d'Ivoire, private land ownership predominates, and households also have access to land through sales(Abdulai et al., 2011; Colin, 2013). Based on our analysis, two sharecropping systems were identified in the study areas. First, land access arrangements where the tenant cultivates food crops and pays the landlord with part of the harvest. In our study, some said to pay 50 to 200 kg of rice or maize depending on the area of the rented land. The second system involved a contract to establish new cocoa or rubber plantations or manage an existing plantation between the usually autochthonous landlord and an allochtone 'caretaker' (Colin, 2013). The complexity of land arrangements under the customary tenure system sometimes results in land conflicts (Adjei-Nsiah et al., 2008; Lambrecht and Asare, 2016), which is an additional constraint to resource-poor farmers. In Ahafo Ano North, we observed that a large area was allocated to one enterprise, and farmers cultivating that land complained they would have to leave the land within a short

period. Insecure access to land is a major factor that prevents farmers from investing in soil fertility and perennial crops (Adjei-Nsiah et al., 2004; Abdulai et al., 2011). Land ownership influences decisions on-farm management, such as the choice of crop and the input use.

2.4.2 Food security and poverty

As expected, rice, both a food and cash crop, was confirmed by the farmers to be the most important crop in all regions, followed by perennial cash crops (cocoa, cashew) and other food crops (maize, yam). In the regions with limited market access, the share of farmers growing rice was significantly larger. The importance of rice, particularly for household consumption, was also highlighted in other studies in West African countries (Giertz et al., 2012; Seck et al., 2012). In this context, the large percentage of farmers renting all their land who cultivated mainly food crops in the inland valley bottom land, suitable for rice cultivation, may explain the importance attached to rice in the study regions. Besides, rice cultivation is stimulated by the demand from elsewhere, with an increasing dietary preference for rice (Balasubramanian et al., 2007), population growth (Seck et al., 2012), and urbanisation (Soullier et al., 2020).

Despite the focus on food crops, in our case specifically rice, a substantial percentage of the farm households in all regions (16-38%) could not meet their minimum daily energy requirements in terms of food availability. This is in line with several other studies suggesting that food insecurity remains widespread in West and East Africa (Hengsdijk et al., 2014; Frelat et al., 2016; Fraval et al., 2019). In Gagnoa, a relatively small percentage of farm households was food insecure compared to the other three regions. Furthermore, many farmers were involved in perennial tree cultivation with high-value produce, except for the landless farmers. Also, farm income tended to be above that in Bouaké for all farm types. Even though there was a higher share of food-secure households, the dietary diversity was less in Gagnoa, both in good and bad seasons. Across all study regions, food crops were the main energy supply, both through direct consumption and sale, as was also observed elsewhere (see, e.g., Frelat et al., 2016; Ritzema et al., 2017). Livestock and wild foods also played a role in human diets.

It was remarkable that households derived their income mainly from farming activities, especially from arable farming. In addition, the contribution of wild foods consumed and sold for FT1 was large. The contributions of livestock and off-farm

activities to income were negligible in all regions. Kuivanen et al. (2016) made a similar observation about the lack of off-farm opportunities in Northern Ghana. This is markedly different from a study by Davis et al. (2017), who reported that rural households in 22 countries in SSA on-farm income contributed on average 63 % to total income. Similar results for SSA were reported by Giller et al. (2021). For instance, off-farm activities contributed around 30 to 40 % to the total income of cocoa farmers in the Western and Brong Ahafo region in Ghana (Wongnaa and Badu., 2020). The high dependence on farming is a risk to the financial and food security of farmers in inland valleys in case of crop failure due to flood events. At the start of the growing season, inland valley farmers focused on soil preparation and bunding, especially in the bottom valley fields for water storage. These are labour-intensive operations. In addition, labour wages were low (Haefele et al., 2000) and hence less attractive for farmers

About half of the surveyed population lived below the poverty line, in Ghana, 42%, and in Côte d'Ivoire, 55%. This is above the national average of about 25% in Ghana (2016) and 40% in Côte d'Ivoire (2018) (World Bank, 2020b). In all regions examined, very few off-farm job opportunities existed. However, it should be noted that the estimation of cash income focused on revenues from crops, livestock, and off-farm income only. We also considered remittances, but they were just minor. Similarly, a recent study by Harris et al. (2021), conducted in five African countries (Mali, Niger, Ethiopia, Burkina Faso, and Kenya), found that the productivity is not sufficient to reach the poverty line ($1.90 per capita per day).

2.5 Ecosystem services

Our results point to some interesting differences in farmers' perceptions of ecosystem services between regions and also highlight similar patterns among farm types.

We observed that provisioning ES, particularly inland valleys' ability to provide food, are considered highly important by farm households of all regions. This is perhaps not surprising since satisfying food needs is a primary concern to farm households, as observed elsewhere (e.g., Lhoest et al. (2019) in Cameroon, Hartter (2010) in Uganda, and Dave et al. (2017) in Madagascar). Farmers' awareness of other provisioning ES differed across regions. In particular, charcoal was important in urban regions (Ahafo Ano South and, to some extent in Bouaké), where it is a scarce resource (Yang et al., 2019). The sparse livestock population explains the low importance of fodder provision. Medicinal plants

are important in Ahafo Ano North and Bouaké, indicating their role in primary health care in these regions, where access to health care services is limited.

So far, little attention has been given to the relevance of ES in developing inland valleys for increasing food production. Our results show that farmers are aware of the relevance of ES for their well-being. We find that farmers in all regions were aware of regulating ES, particularly climate regulation, water storage, groundwater, and insect pollination. This demonstrates that water is particularly vital for farm households in inland valleys. It is also crucial for rice production and food security, as rice strongly depends on water availability in the valley bottom (Egoh et al., 2012). Furthermore, farmers who perceive the benefits of pollination services provided by insects may refrain from using insecticides (Zhang et al., 2016). In contrast, inland valleys modulate floods and reduce flood hazards caused by heavy precipitation events through reducing the runoff fraction, which seems to be of minor importance to all farm types. This may be explained by keeping in mind that farmers producing in or around inland valleys are experienced with flood events. Besides, most of the inland valleys in our sample were not well developed, and the water management systems were poor. Soil formation was well perceived by farmers across regions and farm types, but it was generally rated low compared to other ES. Farmers' awareness of cultural ES was observed to be low compared to the other two categories. In Bouaké, farmers' awareness of the cultural ES tourism was relatively stronger than in the other regions. This contrasts with studies arguing that African communities generally attribute a high value to land as a means for strengthening cultural identity (Cocks et al., 2012; Egoh et al., 2012).

We observe a significant positive correlation between farmers' awareness of provisioning, regulating, and cultural ES. Provisioning ES had a strong relationship with regulating ES, and regulating ES had a strong relationship with supporting ES. This illustrates that farmers recognise the need to maintain a balance between ecosystem services in order to ensure the long-term sustainability of ecosystems. It is important to note, however, that the detailed relationships between individual ecosystem services cannot be explained by simple correlations alone but would require further research.

Our analysis does not provide an exhaustive picture of farming systems and cannot claim to be representative for all West African countries, nor for the whole of Ghana and Côte d'Ivoire. The RHoMIS survey is a one-off survey and uses cross-sectional data based

on farm household recall. As such, it cannot fully capture the highly dynamic and complex structure of farming systems in West African inland valleys. The contribution of our study is to provide interesting new insights into the diversity of inland valley farming systems in West Africa, and about current practices of farm households in the selected regions. Furthermore, our results offer a comprehensive picture of food security, poverty, and farmers' awareness of ecosystem services in these regions. This lays the grounds for exploring long-term strategies for sustainable agricultural development of West African inland valleys.

2.6 Conclusions

Our study of inland valleys revealed important new insights concerning the diversity of farming systems and the importance of ecosystem services. The defined farm types differed more between regions than within regions. The main differences within regions were related to land tenure. Land ownership encouraged the cultivation of perennials, although, in Côte d'Ivoire, management arrangements between landowners and land users opened up opportunities for perennial crops and sometimes for cultivating even large pieces of land. Hence, the variation in farm size within the four farm types was large, and so was the variation in income and potential food availability.

Arable farming was the most prominent contributor to food security and household income, with few alternative job opportunities. In all regions, rice was perceived to be the most important crop, contributing to both household food and cash provision. However, a substantial part of households could not meet their daily energy requirements, and about half was below the poverty line in all regions.

Most farmers were aware of the relevance of food provisioning by inland valleys on their well-being. Furthermore, farmers clearly perceived the role of regulating ES for food production. The awareness of other ES differed between regions, reflecting the specific local conditions of farmers' livelihoods. Farm households' awareness of cultural ES was low compared to the other three categories of ES.

Overall, our findings indicate that interventions to improve national rice production need to acknowledge and preserve the diversity of ecosystem services that inland valleys provide to smallholder farm households. More detailed research is needed to assess what

portfolio of management practices may work best for what kind of farm type to increase agricultural production while preserving ecosystem services.

Acknowledgments

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Supplementary material Chapter 2

Supplementary **Table 2.1**: Ecosystem services of inland valley wetlands used in the 2018-2019 survey

Provisioning ecosystem services	Regulating ecosystem services	Supporting ecosystem services	Cultural ecosystem services
Food (crops, livestock, fishing)	Climate regulation	Soil formation	Handicraft
Firewood and charcoal	Water storage		Aesthetic value
Fodder for livestock	Waste treatment		Recreational value
Construction material	Flood prevention		Educational value
Water sources for domestic use	Groundwater recharge		Religious value
Habitat provision	Erosion prevention		Tourism
Medicinal plants	Pollination (insects)		

Source: Costanza et al. (2017), MEA (2005), Wangai et al. (2016) and feedback from the farm households during the pre-testing survey

Supplementary **Table 2.2**: Mean rank and rank of cultivated crops importance across regions

	Côte d'Ivoire		Ghana	
	Bouaké (n=226)	Gagnoa (n=135)	Ahafo Ano North (n=184)	Ahafo Ano South (n= 188)
Crops	Mean rank (Rank of importance)	Mean rank (Rank of importance)	Mean rank (Rank of importance)	Mean rank (Rank of importance)
Rice	11.81 (1)	12.68 (1)	11.56 (1)	12.17 (1)
Cacao	-	10.22 (2)	11.16 (2)	10.49 (3)
Maize	7.44 (8)	7.50 (4)	10.87 (3)	10.72 (2)
Rubber	-	8.25 (3)	-	-
Plantain	-	6.51 (14)	9.35 (4)	8.09 (7)
Cabbage	7.38 (12)	-	9.28 (5)	7.90 (10)
Garden egg	7.41 (10)	-	9.12 (6)	7.72 (11)
Cassava	10.52 (4)	6.83 (6)	9.04 (7)	8.65 (4)
Pepper	7.38 (13)	-	8.86 (8)	8.11 (6)
Okra	7.39 (11)	6.86 (5)	8.68 (9)	8.55 (5)
Bell pepper	7.41 (9)	-	-	-
Tomato	9.56 (5)	6.60 (8)	8.49 (10)	8.05 (8)
Coffee	-	6.65 (7)	-	-
Palm oil	7.34 (14)	6.60 (8)	8.15 (11)	7.92 (9)
Sugarcane	-	-	8.14 (12)	-
Coconut	-	-	8.10 (13)	-
Yam	11.32 (2)	6.60 (8)	8.09 (14)	7.54 (14)
Cowpea	-	-	8.05 (15)	7.59 (12)
Coco Yam	-	-	8.05 (15)	7.50 (15)
Beans	7.34 (14)	-	8.01 (17)	-
Cucumber	7.62 (6)	6.60 (8)	-	7.58 (12)
Groundnut	7.51 (7)		-	7.42 (16)
Cashew	11.25 (3)	6.51 (13)	-	-
Sweet potato	-	6.59 (12)	-	-
Kendall's W	0.348	0.521	0.164	0.246
Chi-square	1227.76	1022.20	485.66	692.83
Asymptotic significance	< .001	< .001	< .001	< .001

Note: Asymptotic significance at $P < .001$. Bold figures in the table show the five major crops ranked.

Supplementary **Table 2.3:** Mean scores (0-5), standard errors, and F-values (ANOVA) for the importance of ES by the farm households in the inland valleys in the four regions based on the household baseline survey (2018-2019)

Ecosystem (ES)	Côte d'Ivoire		Ghana		F-test	P-value
	Bouaké (n=226)	Gagnoa (n=135)	Ahafo Ano North (n=184)	Ahafo Ano South (n= 188)		
	Mean ±SE	Mean ± SE	Mean ± SE	Mean ± SE		
(A) Provisioning ES						
Food (crops, livestock, fishing	4.49±0.04^{a}	4.79±0.04^{b}	4.76±0.04^{b}	4.79±0.04^{b}	12.04	< 0.001
Firewood and charcoal	3.58±0.06^{a}	2.85±0.08^{b}	3.34±0.07^{a}	3.47±0.075^{a}	16.44	< 0.001
Fodder for livestock	3.18±0.06^{b}	2.48±0.07^{a}	2.31±0.07^{a}	3.20±0.06^{b}	44.03	< 0.001
Construction material	3.08±0.06^{b}	2.64±0.08^{a}	2.53±0.07^{b}	2.98±0.07^{b}	13.47	< 0.001
Water sources for domestic use	3.19±0.06^{a}	3.27±0.08^{a}	3.32±0.07^{a}	3.82±0.07^{b}	15.93	< 0.001
Home for habitat	3.41±0.06^{b}	2.54±0.08^{a}	2.65±0.07^{a}	2.96±0.07^{b}	31.2	< 0.001
Medicinal plants	3.73±0.06^{a}	3.15±0.08^{b}	2.85±0.07^{b}	3.78±0.07^{a}	38.98	< 0.001
(B) Regulating ES						
Climate regulation	3.02±0.07^{a}	3.62±0.09^{bc}	3.31±0.08^{ab}	3.71±0.08^{c}	14.02	< 0.001
Water storage	3.62±0.06^{a}	3.73±0.07^{a}	3.47±0.07^{a}	4.21±0.06^{b}	22.23	< 0.001
Waste treatment	2.94±0.05^{c}	2.62±0.07^{a}	2.11±0.06^{b}	2.43±0.06^{a}	32.74	< 0.001
Flood prevention	2.97±0.06^{a}	2.85±0.080^{a}	2.88±0.07^{a}	2.94±0.07^{a}	3.41	< 0.217
Groundwater recharge	3.54±0.06^{a}	2.87±0.76^{b}	3.53±0.06^{a}	3.97±0.06^{a}	38.87	< 0.001
Erosion prevention	2.77±0.06^{b}	2.50±0.07^{a}	2.68±0.07^{ab}	3.04±0.07^{c}	9.35	< 0.001
Pollination (insects)	2.83±0.07^{a}	2.66±0.09^{a}	3.15±0.08^{b}	3.39±0.08^{b}	14.53	< 0.001
(C) Supporting ES						
Soil formation	3.79±0.06^{a}	4.14 ±0.07^{b}	3.80 ±0.07^{a}	4.25±0.07^{b}	11.59	< 0.001
(D) Cultural ES						
Handicraft	2.80±0.06^{b}	2.23±0.07^{a}	2.38±0.07^{a}	2.94±0.07^{b}	21.36	< 0.001
Aesthetic value	3.25±0.06^{b}	2.39±0.08^{a}	2.53±0.07^{a}	2.57±0.07^{a}	31.35	< 0.001
Recreational value	3.65±0.06^{c}	2.63±0.07^{b}	2.54±0.06^{ab}	2.31±0.06^{a}	90.72	< 0.001
Educational value	3.02±0.06^{b}	2.54±0.08^{a}	2.49±0.07^{a}	2.60±0.07^{a}	12.56	< 0.001
Religious value	2.30±0.06^{a}	2.12±0.07^{a}	2.72±0.07^{b}	2.33±0.07a	11.55	< 0.001
Tourisms	2.84±0.05^{b}	2.41±0.07^{a}	2.15±0.06^{c}	2.42±0.06^{a}	22.76	< 0.001

Note: a-c: Mean values followed by different letters in rows are different at Bonferroni-adjusted significant level $P \leq 0.05$ (post hoc tests with Bonferroni correction for multiple comparisons).

Supplementary **Table 2.4**: Spearman's correlation coefficients between ecosystem services

Ecosystem services (ES)	Ecosystem services			
	Provisioning	Regulating	Cultural	Supporting
Provisioning	1.00	0.57***	0.54***	0.35***
Regulating		1.00	0.43***	0.67***
Cultural			1.00	0.18
Supporting				1.00

Significant at $P \leq 0.01$ for all correlation coefficients.

Supplementary **Table 2.5**: Mean scores, standard errors, and p-values (ANOVA) for the importance ES by the farm households for the four farm types in the regions in Côte d'Ivoire, based on the household baseline survey (2018-2019)

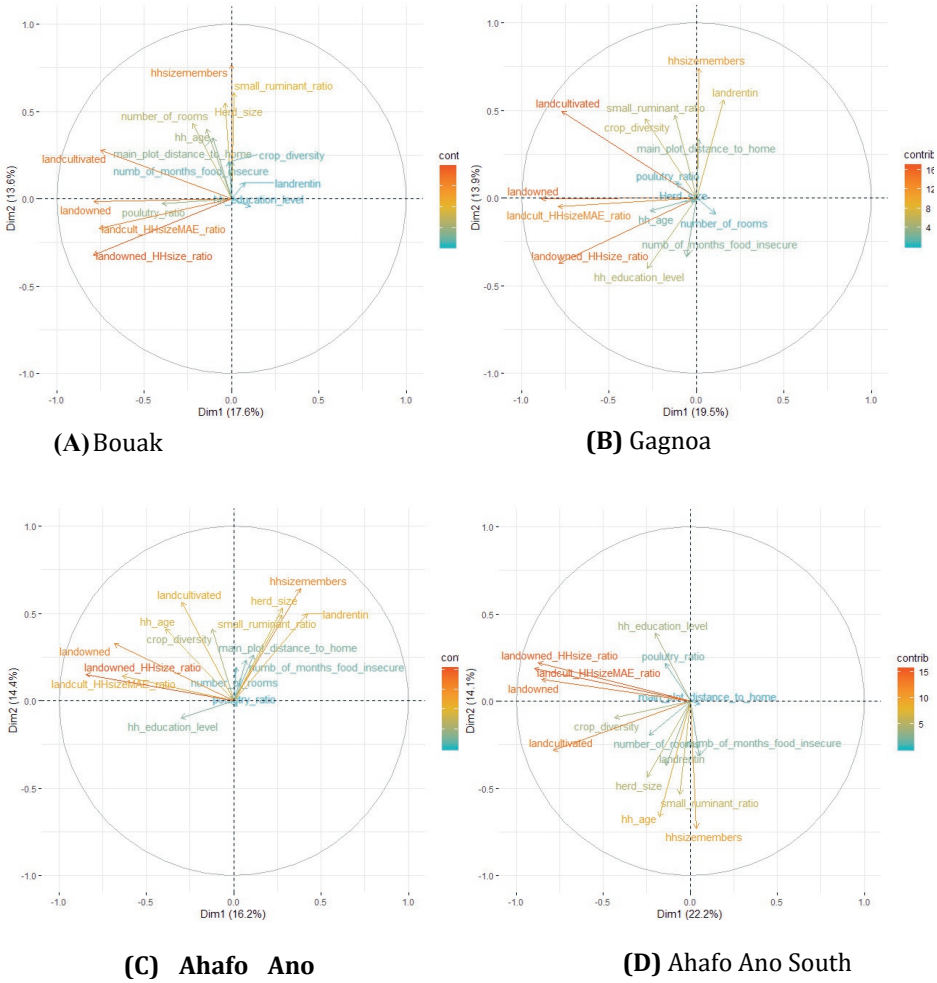
Ecosystems (ES)	Côte d'Ivoire									
	Bouaké					Gagnoa				
	FT1(n=25)	FT2(n=14)	FT3 (n=38)	FT4 (n=149)	*P*-value	FT1(n=38)	FT2(n=18)	FT3 (n=43)	FT4 (n=36)	*P*-value
	Mean ±SE	Mean ±SE	Mean ±SE	Mean ±SE		Mean ±SE	Mean ±SE	Mean ±SE	Mean ±SE	
(A) Provisioning ES										
Food (crops, livestock, fishing)	4.42±0.15^{a}	4.50±0.21^{a}	4.27±0.12^{a}	4.56±0.06^{a}	0.207	4.74±0.07^{a}	4.77±0.10^{a}	4.79±0.07^{a}	4.89±0.08^{a}	0.580
Firewood and charcoal	3.65±0.18^{ab}	3.42±0.25^{ab}	3.15±0.14^{a}	3.69±0.07^{b}	0.013	2.63±0.14^{a}	3.22±0.21^{a}	2.83±0.144^{a}	2.91±0.16^{a}	0.148
Fodder for livestock	3.30±0.20^{a}	3.0±0.27^{a}	3.12±0.16^{a}	3.19±0.08^{a}	0.812	2.53±0.11^{a}	2.09±0.16^{a}	2.52±0.11^{a}	2.62±0.13^{a}	0.083
Construction material	3.0±0.20^{a}	3.0±0.28^{a}	2.87±0.16^{a}	3.16±0.08^{a}	0.461	2.46±0.12^{a}	2.86±0.18^{a}	2.81±0.12^{a}	2.54±0.14^{a}	0.133
Water sources for domestic use	3.42±0.18^{a}	3.14±0.25^{a}	3.0±0.15^{a}	3.21±0.07^{a}	0.368	3.17±0.13a	3.09±0.19a	3.39±0.13^{a}	3.35±0.14^{a}	0.455
Home for habitat	3.53±0.19^{a}	3.07±0.26^{a}	3.30±0.15^{a}	3.46±0.07^{a}	0.384	2.42±0.11^{a}	3.04±0.17^{b}	2.41±0.11^{a}	2.56±0.13^{ab}	0.015
Medicinal plants	3.69±0.20^{ab}	3.71±0.27^{ab}	3.27±0.16^{a}	3.86±0.08^{b}	0.016	3.12±0.13^{a}	3.12±0.13^{a}	3.16±0.13^{a}	2.97±0.15^{a}	0.219
(B) Regulating ES										
Climate regulation	2.80±0.26^{a}	2.57±0.36^{a}	2.87±0.21^{a}	3.14±0.10^{a}	0.28	2.97±0.15^{a}	4.22±0.23^{b}	3.91±0.15^{b}	3.70±0.18^{b}	**0**.001
Water storage	3.88±0.17^{b}	3.28±0.24^{ab}	3.25±0.14^{a}	3.70±0.07^{b}	0.008	3.68±0.12^{a}	3.86±0.18^{a}	3.77±0.12^{a}	3.67±0.14^{a}	0.828
Waste treatment	3.15±0.22^{ab}	2.78±0.29^{ab}	2.42±0.17^{a}	3.05±0.08^{b}	0.011	2.82±0.12^{a}	2.36±0.18^{a}	2.60±0.12^{a}	2.56±0.14^{a}	0.183
Flood prevention	3.19±0.20^{b}	3.0±0.27^{ab}	2.35±0.16^{a}	3.08±0.08^{b}	0.001	2.95±0.12^{a}	2.72±0.17^{a}	2.93±0.12^{a}	2.70±0.13^{a}	0.399
Groundwater recharge	3.65±0.18^{a}	3.71±0.25^{a}	3.22±0.14^{a}	3.58±0.07^{a}	0.129	2.72±0.14^{a}	3.18±0.20^{a}	2.95±0.13^{a}	2.78±0.15^{a}	0.255
Erosion prevention	2.88±0.20^{ab}	3.0±0.27^{ab}	2.22±0.16^{a}	2.87±0.08^{b}	0.004	2.38±0.12^{a}	2.77±0.17^{a}	2.52±0.12^{a}	2.45±0.14^{a}	0.328
Pollination (insects)	2.61±0.24^{a}	2.64±0.33^{a}	2.72±0.20^{a}	2.91±0.10^{a}	0.560	2.57±0.14^{a}	2.95±0.21^{a}	2.64±0.14^{a}	2.62±0.16^{a}	0.505
(C) Supporting ES										
Soil formation	3.88±0.21^{b}	3.85±0.28^{ab}	3.15±0.17^{a}	3.94±0.08^{b}	0.08	4.13±0.11^{a}	3.95±0.16^{a}	4.26±0.11^{a}	4.11±0.12^{a}	0.46
(D) Cultural ES										
Handicraft	2.76±0.19^{a}	2.64±0.26^{a}	2.47±0.15^{a}	2.91±0.08^{a}	0.096	2.12±0.11^{a}	2.40±0.17^{a}	2.27±0.11^{a}	2.21±0.13^{a}	0.582
Aesthetic value	3.23±0.20^{a}	2.78±0.28^{a}	3.18±0.16^{a}	3.31±0.08^{a}	0.327	2.38±0.15^{a}	2.45±0.22^{a}	2.54±0.14^{a}	2.18±0.16^{a}	0.475
Recreational value	3.46±0.18^{a}	3.85±0.25^{a}	3.47±0.15^{a}	3.71±0.07^{a}	0.296	2.82±0.15^{b}	2.81±0.22^{ab}	2.70±0.15^{ab}	2.18±0.17^{a}	0.034
Educational value	3.07±0.21^{a}	3.28±0.29^{a}	3.10±0.17	2.96±0.08^{a}	0.695	2.76±0.14^{a}	2.77±0.21^{a}	2.45±0.14^{a}	2.24±0.16^{a}	0.069
Religious value	2.03±0.20^{a}	2.5±0.27^{a}	2.3±0.16^{a}	2.33±0.08^{a}	0.505	2.02±0.10^{a}	2.0±0.15^{a}	2.20±0.10^{a}	2.24±0.11^{a}	0.342
Tourisms	2.88±0.20^{a}	3.14±0.27^{a}	2.7±0.16^{a}	2.84±0.08^{a}	0.581	2.5±0.13^{a}	2.27±0.18^{a}	2.43±0.13^{a}	2.35±0.14^{a}	0.722

Note: **a-b:** Mean values followed by different letters are different at Bonferroni-adjusted significant level $P \leq 0.05$ (post hoc tests with Bonferroni's correction for multiple comparisons).

Supplementary **Table 2.6**: Mean scores, standard errors, and p-values (ANOVA) for the importance ES by the farm households for the four farm types in the regions in Ghana, based on the household baseline survey (2018-2019)

Ecosystems (ES)	Ghana									
	Ahafo Ano north					Ahafo Ano south				
	FT1(n=120)	FT2 (n=10)	FT3 (n=23)	FT4 (n=31)	*P*-value	FT1 (n=117)	FT2 (n=13)	FT3 (n=35)	FT4 (n=23)	*P*-value
	Mean ±SE	Mean ±SE	Mean ±SE	Mean ±SE		Mean ±SE	Mean ±SE	Mean ±SE	Mean ±SE	
A. Provisioning ES										
Food (crops, livestock, fishing)	4.82±0.05^{a}	4.60±0.19^{a}	4.62±0.12^{a}	4.67±0.10^{a}	0.280	4.78±0.04^{a}	4.76±0.12^{a}	4.70±0.07^{a}	4.95±0.09^{a}	0.236
Firewood and charcoal	3.31±0.09^{ab}	3.50±0.33^{ab}	2.91±0.21^{a}	3.70±0.18^{b}	0.047	3.45±0.10^{a}	3.69±0.32^{a}	3.41±0.19^{a}	3.52±0.24^{a}	0.887
Fodder for livestock	2.26±0.06^{a}	2.20±0.22^{a}	2.25±0.14^{a}	2.61±0.12^{a}	0.093	3.20±0.10^{a}	3.84±0.32^{a}	3.08±0.19^{a}	3.0±0.24^{a}	0.177
Construction material	2.52±0.08^{a}	2.60±0.28^{a}	2.41±0.18^{a}	2.64±0.16^{a}	0.812	3.02±0.10^{a}	2.84±0.31^{a}	2.85±0.19^{a}	3.04±0.23^{a}	0.833
Water sources for domestic use	3.38±0.10^{a}	3.40±0.35^{a}	3.37±0.22^{a}	3.09±0.20^{a}	0.659	3.90±0.08^{a}	3.69±0.26^{a}	3.67±0.16^{a}	3.65±0.19^{a}	0.425
Home for habitat	2.65±0.1^{a}	2.50±0.32^{a}	2.54±0.20^{a}	2.83±0.18^{a}	0.667	3.04±0.10^{a}	3.46±0.31^{a}	2.64±0.19^{a}	2.73±0.23^{a}	0.082
Medicinal plants	2.80±0.08^{a}	2.90±0.30^{a}	2.87±0.19^{a}	3.03±0.17^{a}	0.696	3.79±0.09^{a}	4.0±0.29^{a}	3.79±0.18^{a}	3.56±0.21^{a}	0.666
B. Regulating ES										
Climate regulation	3.26±0.08^{a}	3.0±0.30^{a}	3.58±0.19^{a}	3.41±0.17^{a}	0.314	3.77±0.11^{a}	3.46±0.34^{a}	3.70±0.21^{a}	3.60±0.25^{a}	0.806
Water storage	3.53±0.10^{a}	3.30±0.35^{a}	3.58±0.22^{a}	3.22±0.19^{a}	0.501	4.15±0.07^{a}	4.23±0.22^{a}	4.38±0.14^{a}	4.26±0.16^{a}	0.561
Waste treatment	2.13±0.03^{a}	2.0±0.13^{a}	2.04±0.08^{a}	2.16±0.07^{a}	0.546	2.48±0.07a	2.30±0.22^{a}	2.29±0.14^{a}	2.47±0.17^{a}	0.598
Flood prevention	2.70±0.08^{a}	2.70±0.28^{a}	2.41±0.18a	2.80±0.16a	0.447	2.88±0.10^{a}	3.38±0.30^{a}	3.14±0.18^{a}	2.73±0.23^{a}	0.220
Groundwater recharge	3.59±0.09^{a}	3.50±0.32^{a}	3.04±0.20^{a}	3.70±0.18^{a}	0.076	4.02±0.07^{a}	4.15±0.23^{a}	3.85±0.14^{a}	3.82±0.17^{a}	0.477
Erosion prevention	2.72±0.08^{a}	2.70±0.28^{a}	2.58±0.18^{a}	2.61±0.16^{a}	0.860	3.08±0.09^{a}	2.84±0.29^{a}	3.17±0.18^{a}	2.73±0.21^{a}	0.377
Pollination (insects)	3.15±0.09^{a}	3.0±0.32^{a}	3.37±0.20^{a}	3.03±0.18^{a}	0.611	3.47±0.11a	3.30±0.34a	3.14±0.21a	3.43±0.26a	0.604
C. Supporting ES										
Soil formation	3.86±0.09^{b}	3.70 ±0.33^{ab}	4.21±0.22^{b}	3.26±0.19^{a}	0.009	4.23±0.73^{a}	3.84±0.22^{a}	4.48±0.13^{a}	4.21±0.16^{a}	0.10
C. Cultural ES										
Handicraft	2.36±0.07^{a}	2.90±0.255^{a}	2.41±0.16^{a}	2.25±0.14^{a}	0.182	2.97±0.10^{a}	3.07±0.32^{a}	2.88±0.20^{a}	2.78±0.24^{a}	0.858
Aesthetic value	2.57±0.08^{a}	2.50±0.28^{a}	2.33±0.18^{a}	2.54±0.16^{a}	0.686	2.67±0.08^{a}	2.61±0.26^{a}	2.29±0.16^{a}	2.43±0.20^{a}	0.207
Recreational value	2.58±0.08^{a}	2.50±0.27^{a}	2.38±0.18^{a}	2.51±0.15^{a}	0.760	2.34±0.06^{a}	2.38±0.20^{a}	2.17±0.13	2.34±0.15^{a}	0.683
Educational value	2.50±0.07^{a}	2.60±0.24^{a}	2.29±0.16^{a}	2.58±0.14^{a}	0.538	2.66±0.09^{a}	2.53±0.29^{a}	2.55±0.18^{a}	2.43±0.21^{a}	0.781
Religious value	2.77±0.10^{a}	2.60±0.37^{a}	2.87±0.24^{a}	2.45±0.211^{a}	0.498	2.32±0.07^{a}	2.69±0.23^{a}	2.38±0.14^{a}	2.13±0.17^{a}	0.294
Tourisms	2.16±0.04^{a}	2.30±0.15^{a}	2.04±0.10^{a}	2.16±0.09^{a}	0.551	2.47±0.08^{a}	2.76±0.25^{a}	2.20±0.15^{a}	2.26±0.18^{a}	0.173

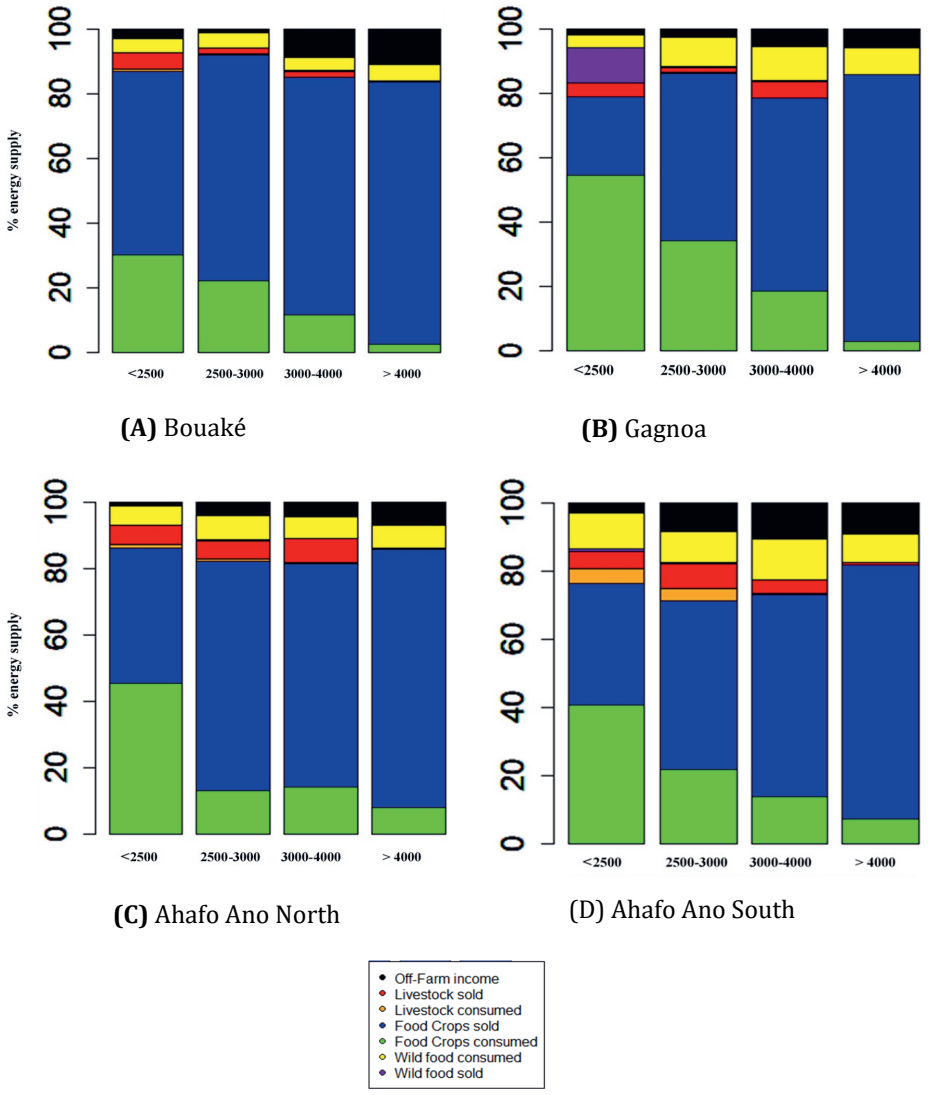
Note: **a-c:** Mean values having different letters are different at Bonferroni-adjusted significant level $P \leq 0.05$ (post hoc tests with Bonferroni's correction for multiple comparisons).



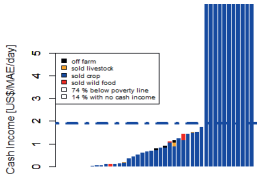
(A) Bouak **(B)** Gagnoa

(C) Ahafo Ano **(D)** Ahafo Ano South

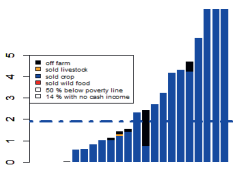
Supplementary **Figure 2.1**: Principal component analysis (PCA) showing farm household variables in (A) Bouaké, (B) Gagnoa, (C) Ahafo Ano North, and (D) Ahafo Ano South.



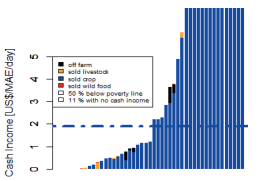
Supplementary **Figure 2.2**: Relative contribution of different sources of livelihood contributing to PFA, per PFA group across regions. The x-axis shows the median food availability value (MAE^{-1} d^{-1}) in each category (lowest, lower-middle, upper-middle, and upper) across the region, where < 2500 kcal MAE^{-1} d^{-1} and > 4000 kcal MAE^{-1} d^{-1} are the lowest and the highest PFA, respectively. The y-axis shows the energy supply in %.



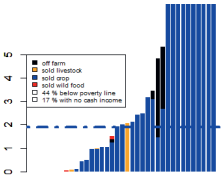
(A) Farm type 1



(B) Farm type 2

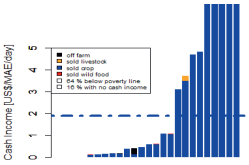


(C) Farm type 3

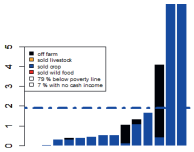


(D) Farm type 4

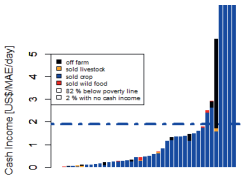
Bouaké



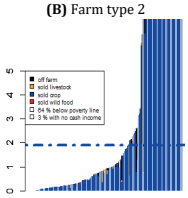
(A) Farm type 1



(B) Farm type 2

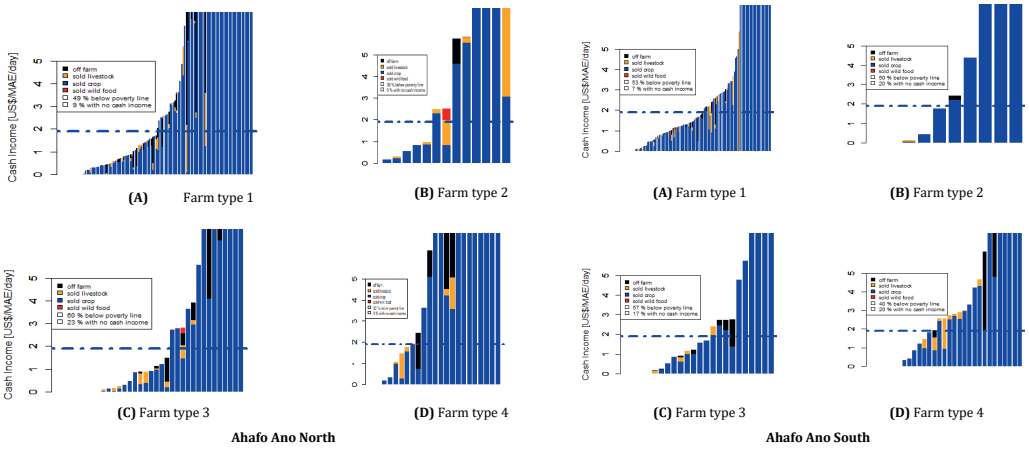


(C) Farm type 3

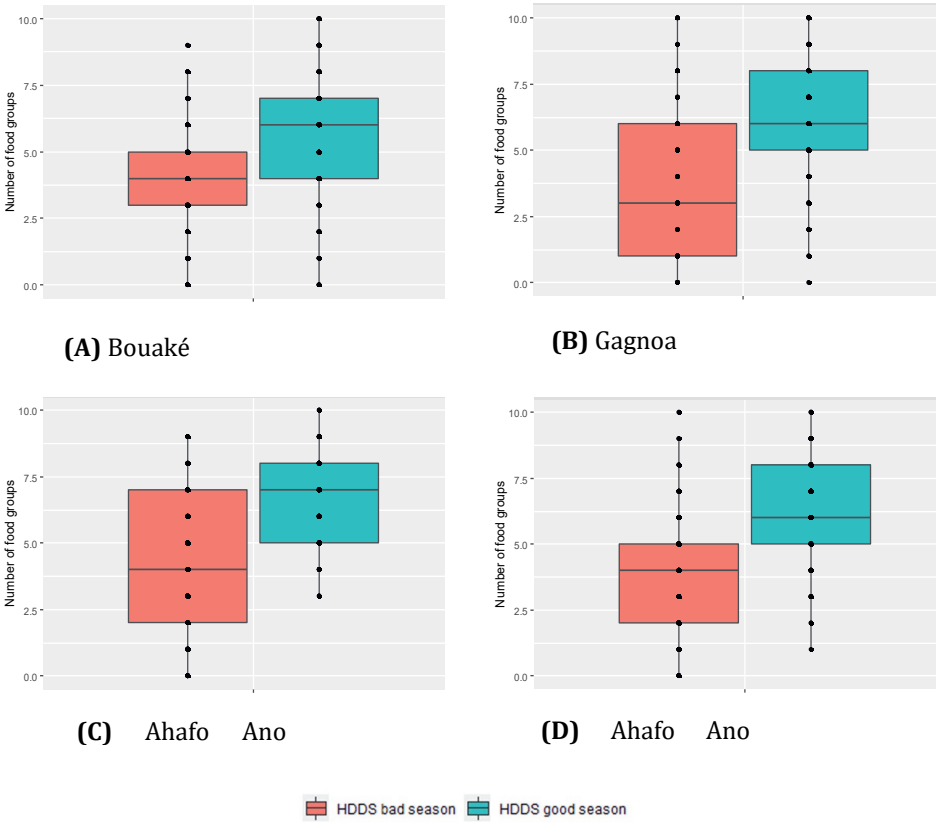


(D) Farm type 4

Gagnoa



Supplementary **Figure 2.4:** Cash income of individual farm households per region per farm type. Individual farm households are ordered on the x-axis. The blue dotted line represents the poverty line of $1.9 person^{-1} day^{-1} based on the World Bank's international poverty line (World Bank, 2017).



Supplementary **Figure 2.5:** Household Dietary Diversity Score (HDDS; the number of food groups consumed) during a good and a bad season in the four regions. The solid black lines denote the median HDDS values.

Chapter 3
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: Inland valley; Rice production; Adoption; Perennial tree crops; Probit; Côte d'Ivoire; Ghana

3.1 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 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 underutilised 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 underutilised 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 analyse the barriers and drivers of the decision to

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

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., 2018a; Djagba et al., 2018b; Dossou-Yovo et al., 2018; Hector et al., 2018; 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. (2018a) 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.

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 analyse 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 organised as follows. Section 2 provides an overview of the conceptual framework, estimation strategy, and econometric model specifications. Section 3 presents the material and methods, including the study area, sampling procedure, survey design, and hypothesised relationships of variables. Sections 4 and 5 present the results and discussion part. The final part presents the conclusions and policy implications.

3.2 Conceptual framework and estimation method

3.2.1 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 labour 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; de 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 maximise 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 analysed 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:

$$U_{ij}^{*} = \beta' x_{ij} + \varepsilon_{ij} \text{ and } U_{ij} = \begin{cases} 1 & \text{if } U_{ij}^{*} > 0 \\ 0, & \text{otherwise} \end{cases} \quad (3.1)$$

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; xij is a vector of explanatory variables, and εij 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.

3.2.2 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):

$$y_{1i}^{*} = \beta' x_{1i} + \varepsilon_{1i}, y_{1i} = 1 \text{ if } y_{1i}^{*} > 0, 0 \text{ otherwise} \quad (3.2)$$

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. x1i is a vector of explanatory variables; β' presents vectors of estimable model parameters; and ε1i 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:

$$y_{2i}^{*} = \gamma' x_{2i} + \varepsilon_{2i}, \; y_{2i} = 1 \; if \; y_{2i}^{*} > 0, 0 \; otherwise, for \; y_{1i} = 1 \quad (3.3)$$

where y*2i represents the latent variable (unobserved). If $y_{2i}^{*} > 0$, farmers choose rice crops; otherwise, they choose non-rice crops. x2i 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 (3.2) and (3.3) using Stata 16.0 (StataCorp, 2019).[2]

3.3 Study area, data, and description of variables

3.3.1 Study area

Differences This study was part of a larger research project coordinated by AfricaRice, a CGIAR Research Centre, 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 3.1 presents a map of the study areas.

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 recognised by the community but not legally secure under formal land laws (Dolcerocca, 2021). 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

[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, D. G., Kupper, L. L., Nizam, A. & Rosenberg, E. S. 2013. *Applied regression analysis and other multivariable methods.* 5th ed. Boston: 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 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.

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 (Niang et al., 2017; Dossou-Yovo et al., 2022; Totin et al., 2022).

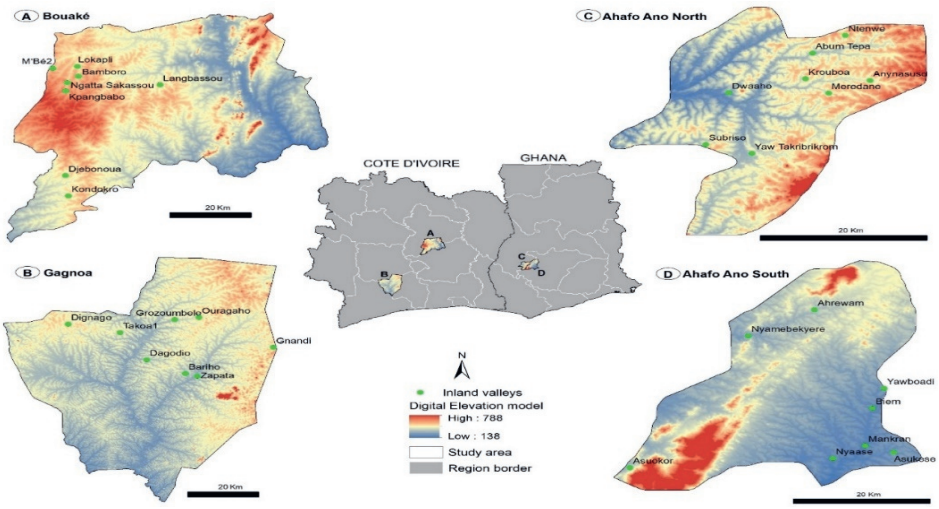


Figure 3.1 Map of the study area

3.3.2 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 standardised, 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 (ODK) 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.

3.3.3 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 categorised into four groups: household characteristics, access to services, physical capital, and regional dummies. Table 3.1 provides the names and definitions of all variables.

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

Table 3.1: 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)

3.3.3.1*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 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., 2019). 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, labour, and cash, and they face more discrimination regarding access to inputs and information, which deters them from adoption (Kassie et

al., 2013). Therefore, we hypothesise that female farmers are less likely to adopt inland valley farming and rice production than male farmers.

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 labour-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 labour availability and hence, farming decisions (Kassie et al., 2013). Farmers with more workers in the household have more labour for agriculture, facilitating the adoption of labour-intensive technologies like rice production while reducing hired labour 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.

3.3.3.2*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 hypothesise 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 labour) needed to farm in inland valleys or produce rice (Rashid, 2021; Ruzzante et al., 2021). Therefore, we hypothesise 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 hypothesise that distance to market is negatively related to the likelihood of adopting inland valley farming and rice production.

3.3.3.3*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 labour-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 labour-intensive (Balasubramanian et al., 2007; Paresys et al., 2018), farmers with a large amount of cultivated land may prioritise 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 labour 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 labour-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 labour. This inflexibility reduces incentives to diversify into more labour-intensive activities, such as inland valley farming or rice production, even when overall income levels are higher. Therefore, we hypothesise 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 labour-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., 2018). 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 labour 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 hypothesise 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 labour-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.

3.3.3.4*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).

3.3.4 Descriptive statistics

Table 3.2 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 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 3.2: Descriptive statistics of variables used in the analysis of adoption of inland valley farming.

	Total sample (n=742)		Inland valley farming: Adopters (n=567)		Inland valley farming: 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.

Table 3.3 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.

Table 3.3: Descriptive statistics of the variables used in the analysis of adoption of rice production, only for households that adopted inland valley farming (n=567).

Variable name	Rice production						
	Sample of adopters of inland valley farming (n=567)		Adopters (n=240)		Non-adopters (n=327)		Mean difference
	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.

3.4 Results

Table 3.4 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 ($\chi2=123.63$, $p < 0.01$) 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 ($\chi2=160.03$, $p < 0.01$).

Table 3.4: Probit model estimates of adoption decision of inland valley farming and rice production.

Explanatory variables	Adoption of inland valley farming (full sample N=742)		Adoption of rice production (subsample of inland valley farming adopters, N=567)	
	(a)		(b)	
	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.

3.4.1 Determinants of adoption of inland valley farming

Column (a) of Table 3.4 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.

3.4.2 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 3.4 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.

3.4.3 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 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, columns 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.

3.5 Discussion

3.5.1 Household characteristics

In subsection "description of variables and hypotheses", we hypothesised 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 labour-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., 2019; 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 emphasised in studies by Bedeke et al. (2021) 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 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.

3.5.2 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 hypothesised 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, fertiliser, 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., 2018a; 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.

3.5.3 Physical capital

As indicated in section 3.3.3, 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 hypothesised 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 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 mechanisation. 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 prioritise 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 emphasised 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 labour-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 labour resources (Sanogo et al., 2023). Farmers with larger livestock holdings may prioritise grazing areas and allocate household labour to livestock management rather than investing in labour-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.

3.6 Conclusion and policy implications

Inland valleys remain significantly underutilised 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.

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, labour, and extension services. It is crucial to recognise 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 recognise 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 Chapter 3

Appendix B. Results from robustness checks

Table B1: Probit model estimates of adoption decision of inland valley farming and rice production.

Explanatory variables	Adoption of inland valley farming (excluding non-household head respondents, N=674)		Adoption of rice production (subsample of inland valley farming adopters and excluding non-household head respondents, N=516)	
	(a)		(b)	
	Coefficient	S.E.	Coefficient	S.E.
Household characteristics				
Age	-0.009*	(0.005)	-0.009*	(0.005)
Gender	0.392***	(0.152)	0.039	(0.244)
Educ	-0.012	(0.012)	-0.010	(0.015)
HHsize	0.011	(0.020)	0.031	(0.023)
Access to services				
Extension	0.234	(0.162)	0.726***	(0.175)
Credit	0.392**	(0.191)	0.162	(0.208)
Mktdist	-0.003*	(0.001)	-0.005***	(0.002)
Physical capital				
lnFarmsize	0.227**	(0.110)	-0.290**	(0.143)
Perencrop	-0.275*	(0.152)	-1.070***	(0.133)
Livestock	-0.050*	(0.029)	0.026	(0.038)
lnTotincome	-0.006	(0.020)	-0.035*	(0.018)
Region dummies				
Bouake	-0.293	(0.345)	0.373	(0.329)
Gagnoa	0.275	(0.188)	0.747***	(0.291)
AnoNorth	0.182	(0.205)	-0.238	(0.337)
Constant	0.618*	(0.394)	0.688	(0.530)
Regression diagnostics				
Log_lik	-341.336		-287.018	
Wald (χ^2)	86.056		225.456	
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.

Chapter 4
Farmers' Preferences for Land Use and Development Attributes: A Choice Experiment Study in Côte d'Ivoire and Ghana

This chapter is based on the manuscript Alemayehu, T., Alpizar, F., van der Lans, I. A., Arouna, A., & Aboudou, R. (2025). Farmers' Preferences for Land Use and Development Attributes: A Choice Experiment Study in Côte d'Ivoire and Ghana.

Abstract

A better understanding of farmers' preferences for alternative land use and development (LUD) attributes should play a central role in the development of sustainable resource use strategies. Yet, scholars and practitioners have a limited understanding of farmers' preferences and the associated trade-offs. This study employs a discrete choice experiment with data from 801 farmers in inland valleys in Côte d'Ivoire and Ghana to investigate farmers' preferences for alternative land use and development (LUD) attributes, including rice productivity, on-farm crop diversity, and biodiversity, all potentially supported by subsidies. Specifically, the analysis examines farmers' preferences for these attributes using willingness to accept welfare measures. Results show that farmers have strong positive preferences for increased rice production and also for diversified on-farm crops. At the same time, farmers, on average, have negative preferences for farming practices that lead to reduced biodiversity compared to the status quo. The livelihoods of inland valley farmers are highly dependent on biodiversity for hunting, fishing, and wild foods. These preferences are reflected in significant welfare measures for said attributes, measured in monetary terms for easy comparison across regions and subjects. The insights provided in this paper show that farmers do perceive a trade-off between biodiversity protection and land productivity, a stated preference that authorities could potentially shape by providing appropriate training and technical assistance.

Keywords: Farmers' preferences; Biodiversity; Discrete Choice experiment; Inland valley; Land use; Preference heterogeneity

4.1 Introduction

Agricultural land in West Africa, like much of sub-Saharan Africa, is under increasing pressure driven by factors such as increasing food demand, arable land scarcity, and soil degradation (Jayne et al., 2014; Touré et al., 2021). Furthermore, ongoing climate change, weather variability, and decreased water availability during the past few decades (Mairura et al., 2021) have led to increased uncertainty among farmers about the timing of cultivation (Giertz et al., 2012). As a result, crop production has been expanding to new areas that were considered not an obvious landscape for agricultural production and traditionally have not often been used for agriculture in sub-Saharan Africa in the past (Verhoeven and Setter, 2010). Inland valleys in West Africa are an example of this type of cultivation area (Dossou-Yovo et al., 2017).

Inland valleys are seasonally flooded wetlands comprised of valley bottoms and their hydromorphic fringes (Rodenburg et al., 2014). Due to higher moisture content and soil fertility, inland valleys have been considered suitable new productive landscapes, particularly for rice-based farming systems (Djagba et al., 2018a), with additional large non-crop benefits for farmers (Rodenburg et al., 2012). Inland valleys provide a good framework to understand farmer preferences for attributes of land use and development (LUD) alternatives in a context where farmers are less affected by the inertia of past decisions.

In West Africa, increasing rice production in the inland valleys has been identified as an effective policy strategy for improving farmers' food security and socio-economic growth (Seck et al., 2013; Tanaka et al., 2017). Specifically, Côte d'Ivoire and Ghana have witnessed land expansion and significant intensification strategies to increase rice production (e.g., Demont et al., 2017).

However, ongoing policy efforts lack evidence on alternative constructions of the landscape and how these relate to the long-term sustainability of inland valley agriculture (e.g., Wood et al., 2013; Rodenburg et al., 2014). Specifically, there are important gaps in the literature that examine farmers' preferences over the use and development of inland valleys and the associated trade-offs (Ortega et al., 2016; Dam et al., 2021). These preferences are likely determined in turn by socio-economic, farm, and institutional factors. However, this potential heterogeneity has not been considered thus far, especially not for the inland valleys of Côte d'Ivoire and Ghana. A better understanding and scientific

assessment of farmers' preferences toward rice productivity and other attributes of inland valleys is imperative as a prior condition for the success of future policies (Rodenburg et al., 2012; Dolinska, 2017).

This paper has two objectives. First, to analyse farmers' preferences for alternative LUD attributes in the context of inland valleys and rice production in Côte d'Ivoire and Ghana. For the sake of comparison, we use a monetary measurement that reflects farmers' monetary trade-offs between specific attributes of inland valley agriculture. Second, we examine how socio-economic, farm, and institutional factors influence these preferences. We use a discrete choice experiment (DCE) method to elicit farmers' preferences for a set of attributes that capture the use and development alternatives in Côte d'Ivoire and Ghana. A random parameter logit model and a model including interaction terms (e.g., Speelman et al., 2015) allow us to explore farmers' heterogeneous preferences under random and conditional factors. Modelling preference heterogeneity is valuable for understanding variations in farmers' preferences and allows policymakers to design more effective, targeted interventions, ensuring that development programs align with farmers' diverse needs and constraints. Additionally, considering heterogeneity offers a more nuanced perspective on how different farmer groups value land use attributes, supporting evidence-based decision-making.

Previous research has shown that inland valleys are suitable for producing various other cereals, vegetables, roots, and tuber crops (Giertz et al., 2012; Touré et al., 2021). It is also believed that crop diversification can improve farmers' well-being by diversifying the seasonal requirements of resources, helping them to increase farm revenue and stabilising farm income over time (Mzyece and Ng'ombe, 2021). Understanding the value of crop diversification from the farmer's perspective is important.

Moreover, inland valley wetlands are biodiversity hotspots (Rodenburg et al., 2014). However, the extensification and intensification of agriculture can deleteriously impact farm biodiversity and undermine crop productivity (Zabel et al., 2019; Plath et al., 2021). Such agriculture-induced biodiversity loss raises concerns about the sustainability of development in this newly established productive landscape (Jaeck and Lifran, 2013). We explore farmers' preferences for biodiversity in and around their plots. A shift in management practices to protect and sustainably manage biodiversity is expected to generate short-term costs to farmers, and a monetary incentive might presumably be

necessary to motivate and boost farmers' participation in the management and conservation process (e.g., Jaeck and Lifran, 2013; Greiner, 2015). Subsidies can encourage conservation activities (Pannell, 2008). The literature widely indicates that in-kind incentives that increase agricultural productivity can encourage farmers' participation in conservation programs (e.g., Richards et al., 2020). The size of the subsidy might differ depending on the alternative characteristics of the proposed intervention. This variation is used in this paper to determine the farmer's valuation of attributes of inland valley agriculture.

The contribution of this study to the literature is threefold. First, it expands our currently limited understanding of management alternatives for African wetlands. The literature on West African inland valley wetlands is particularly scant, yet these valleys differ fundamentally from wetlands in other regions of the world regarding their biophysical, socio-cultural, and institutional context. Second, it provides an approach to modelling the trade-offs farmers are willing to accept when considering different attributes of LUD alternatives. The use of a DCE allows us to put those trade-offs in the form of a monetary willingness to accept measures, which can then be compared between, for example, farmers, subregions, and similar, related studies. There are many applications of the DCE methods to wetlands in Europe and Asia (e.g., Birol et al., 2006; Birol et al., 2009; Westerberg et al., 2010; Hassan et al., 2019; Wei et al., 2021). Wetland valuation has evolved significantly over the years, initially concentrating on wetlands' economic and ecological functions (e.g., Costanza et al., 1997). Since the 2000s, there has been a growing focus on the institutional aspects of wetland management (e.g., Turner et al., 2000). To date, there are only a few applications of the DCE methods to wetlands in Africa, including, for example, those by Speelman et al. (2015) on Kilombero wetlands in Tanzania, East Africa. To the best of the authors' knowledge, the application of DCE to assess farmers' preferences for key policy and context-related use and development attributes of West African inland valley has not been done so far. Our study contributes to assessing farmers' preferences for land use and development in West African inland valleys.

Third, it expands our understanding of the key determinants influencing farmers' preference heterogeneity towards attributes of land use alternatives. Understanding farmers' preferred LUD attributes can help identify context-appropriate practices that

farmers will adopt more successfully. Adopting such practices can support sustainable yield increases, a more diverse production system, and decreased production risk.

The rest of this paper is organised as follows. The next section, Study Area, explains the description of the study areas. Section 3 on Methods presents materials and methods, including an overview of the DCE, sampling procedure, and econometric modelling. This is followed by the Results and Discussion section. The final section presents the Conclusions and Policy Implications.

4.2 Study areas

This study was part of a larger research project coordinated by AfricaRice (a CGIAR Research Centre) to study the potential of the inland valley for food and nutrition security for smallholder farmers in West Africa. We collected data in two regions (Bouake and Gagnoa) in Côte d'Ivoire and two regions (Ahafo Ano North and Ahafo Ano South) in Ghana (Figure 4.1). 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 Côte d'Ivoire at 7° 41' N and 5° 01' W and is located in a humid green forest agroecological zone (AEZ) with annual rainfall ranging from 1300-2300 mm; the region's main economic activity is subsistence farming and is marked by subsistence production (National Institute Statistics, 2014). Gagnoa is located in Côte d'Ivoire's South-central area at 6° 7' N and 5° 57' W. It is located in a humid, dense forest in AEZ. The annual rainfall ranges from 1400-2500 mm; the economy is based on agriculture and mainly on cash crops (National Institute Statistics, 2014). Ahafo Ano North is located in the North-Western part of Ghana at 6° 47' N and 2° 26' W. It lies in a primarily moist deciduous forest AEZ with a mean annual rainfall of 1750 mm and a mean temperature of 28°C; the main occupation of the people is farming, where agriculture alone employs nearly 70% of the total labor force, both direct and indirect (Ghana Statistical Services, 2014). Ahafo Ano South is located in the North-Western part of Ghana at 6° 42' N and 1° 45' W. It lies within the semi-deciduous forest belt AEZ with a mean annual rainfall between 1700-1850 mm. The economy is based on farming, where about 76% of the working population is estimated to be engaged in agriculture (Ghana Statistical Services, 2014).

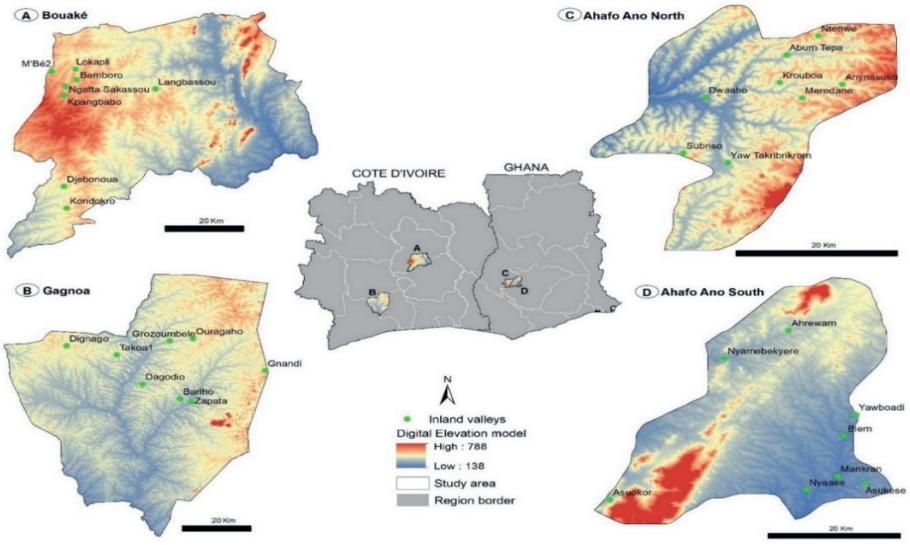


Figure 4.2. Map of the study area.

4.3 Methodological framework

4.3.1 Discrete choice experiment

A DCE is a survey based stated preference method that asks respondents to choose goods, services, or policies from choice sets containing various multi-attribute options (Alpizar et al., 2001; Johnston et al., 2017). DCE is a preferred method for goods, services, or policies that are hypothetical and not available in the market or implemented yet (Louviere et al., 2000). The ability to place respondents into situations in which they must make trade-offs among multiple attributes is an attraction of the DCEs over other stated preference methods (Boxall et al., 2009). Thus, this study employed DCE methods to elicit farmers' preferences for the attributes of LUD alternatives described in terms of combinations of attributes and levels.

4.3.1.1 *Attributes and levels selection*

We identified attributes and attribute levels using multi-stage steps. First, we reviewed existing studies that followed a similar approach to examining farmers' preferences for goods and services (e.g., Speelman et al., 2015; Tarfasa et al., 2018; Walsh et al., 2020). From the review, we identified an initial list of attributes. Second, we organised one focus group discussion per inland valley with farmers working in the inland valleys, and we further validated and refined the list of attributes. Third, we consulted agricultural

economists and agronomists at AfricaRice and experts from national partner institutions to get feedback on the attributes and levels. Their feedback was incorporated, particularly on the phrasing of the attributes and levels. Finally, we selected four attributes that appeared important for LUD decisions and were credible and understandable by farmers.

The attribute levels of the status quo were determined based on empirical data from the socio-economic and agronomic survey by e.g., Alemayehu et al. (2022) and further validated through a literature review (e.g., Rodenburg and Saito, 2022) and expert consultations. Specifically, most farmers reported average rice productivity of 2 tons per hectare and on-farm crop diversity of 2 crops per cropping season. Regarding biodiversity, focus group discussions consistently highlighted perceived low biodiversity across different groups as a current situation. The absence of a structured subsidy program and insights from focus group discussions indicating that most farmers do not receive subsidies for inland valley rice farming further justified assigning 'no subsidy' as the status quo level.

Table 4.1 gives a brief overview of the attributes and their levels. Detailed information containing the list of attributes and their levels with their definition are presented in Table 4.S1 in the *Supplementary Materials*.

Table 4.1: Attributes and corresponding levels.

Attribute	Attribute levels
Rice productivity	2 tons/ha [a]; At least 3 tons/ha; At most 1 tons/ha
On-farm crop diversity	Two crops [a]; Three crops; Five crops
Biodiversity resulting from alternative cultivation practices (BD)	The number of native trees, wild animals, and other plant and animal species will… - [stay low (same) [a]. This is because you are not working on biodiversity conservation measures.] - [improve and increase by half from the current level (higher). However, it is required from you to implement more biodiversity conservation measures.] - [worsen and decline by half (lower). This is because you will focus on rice production and unsustainable exploitation of inland valley resources.]
Subsidy	You will receive a subsidy of x kg of NPK + y kg of Urea fertiliser from your government annually applied to one hectare. This is equivalent to… - Example of x and y: 50kg NPK + 50kg Urea - …0$/year[a]; 65$/year; 130$/year; 195$/year; 255$/year;

Notes: [a] The status quo level (SQ). [b] The subsidy attribute is an in-kind fertiliser subsidy. Its equivalent monetary values were converted into purchasing power parity (PPP) corrected in US$ for the WTA analysis.

The first attribute is rice productivity. It refers to the average yield of rice production in tons per hectare (tons/ha). This attribute is considered necessary because rice is a staple food for many farmers in the study areas, and increasing rice yield is needed for farmers to meet the food demand of their families and enhance their livelihood and economic performance (Seck et al., 2013; Tanaka et al., 2017). This attribute has also been included in other preference studies (e.g., Oyinbo et al., 2019; Sanou et al., 2019) and found to be relevant. Three levels were defined for this attribute (Table 4.1) and carefully selected based on the realistic rice yields in the study areas (Niang et al., 2017).

The second attribute is on-farm crop diversity. It indicates the potential number of crops grown on the farm. This attribute is important for farmers because, in the inland valleys, apart from rice, many crops are widely grown to increase income and reduce farmers' risks (e.g., Giertz et al., 2012). Some farmers prioritise other crops over rice due to their profitability (Krupnik et al., 2012). We have learned in our focus group discussions that farmers prefer crops and crop varieties adapted to the local environmental conditions, such that they can provide stable yields and improve the genetic diversity of the crop farming system. Other preference studies also included this attribute (e.g., Häfner et al., 2017). Three levels were defined (Table 4.1) based on our

focus group discussions and the literature, which both revealed that considerable opportunity exists for growing more than two crops in addition to rice in the inland valleys (Adigbo et al., 2007).

The third attribute is biodiversity resulting from alternative farm management practices. Specifically, we refer to the prevalence of different plants, trees, and animal species in and around the inland valleys resulting from agricultural practices that focus on rice production or take a more environmentally friendly approach to on and off-farm management (EFAP[5]). Inland valleys are essential for water storage, climate hazard buffer zones, and biodiversity hot spots, and many farm households' livelihoods depend on biodiversity for hunting, fishing, forage, forest, and other ecosystem services (e.g., Rodenburg et al., 2014). In other wetland management and landscape preference studies (e.g., Speelman et al., 2015; Hassan et al., 2019), biodiversity was found to be an important attribute. Based on previous studies and the focus group discussion, we decided to allocate three levels to this attribute (higher, same, and lower; see Table 4.1 and Table 4.S1 for a detailed description of this important attribute).

The fourth attribute is an in-kind subsidy of NPK and urea (key fertilisers) provided by the government as an incentive for boosting farmers' participation in biodiversity conservation measures and compensation for potential short-term costs of farmers. In this study, fertiliser is provided once every year if biodiversity conservation measures are implemented as described in the choice set. The amount of fertiliser is per hectare and can easily be converted into monetary 'implicit' prices. Previous studies also used this attribute (e.g., Wang et al., 2018; Hassan et al., 2019; Nong et al., 2021). This attribute has five levels. The levels of the subsidy attribute are calculated based on the recommended fertiliser rate for the inland valleys (Bado et al., 2018), and here we describe the monetary equivalent values for brevity.

4.3.1.2*Discrete choice experiment design*

For the DCE, we generated a design with 30 choice sets using SAS macros that maximise D-efficiency under zero priors, as outlined in Kuhfeld (2010). Every choice set consisted

[5] EFAP– Environmentally Friendly Agricultural Practices includes practices, such as organic farming, to both grow crops and minimize negative environmental impacts (e.g., pesticide pollution, greenhouse gas emissions, soil erosion, and degradation of the resource base).

of three potential alternatives (two hypothetical and a status quo). Each alternative contained four attributes that differed in their levels (Figure 4.2). We split the 30 choice sets into six blocks with five choice sets each, corresponding with six different versions of the questionnaire.

Each farmer was randomly allocated to a version of the questionnaire and asked to choose the most preferred one from the three alternatives in each of the five-choice sets. Besides the choice scenario, the questionnaire also contained questions on farmers' demographics, socio-economic, institutional, and attitudinal questions related to biodiversity, and debriefing questions. We translated the attribute and attribute level descriptions and all sections of the questionnaire into the local language to ensure participants' understanding. A survey questionnaire translated into the local language was read to the respondent. Moreover, we used colour-printed visual images illustrating the attribute levels to make it easier for survey participants to perceive the attributes and levels. Figure 4.2 provides an example of a choice set. Moreover, we provided an example of the description of the choice set, which explains the two alternatives and status quo LUD in Box 4.S1 in the *Supplementary Materials*.

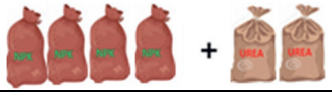
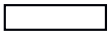
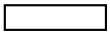
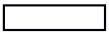
Attributes	Alternative 1	Alternative 2	Status quo
Rice productivity (RP)	At most 1 ton/ha 	At least 3 tons/ha 	2 tons/ha 
On-farm crop diversity (CD)	5 crops 	2 crops 	2 crops 
Biodiversity resulting from alternative cultivation practices (BD)	50% improvement due to EFAP 	50% decline due to management practices that focus only on rice production 	Low due to existing agricultural practices 
Subsidy (SD)	255$ year^{-1} ≈ 200kg NPK + 100kg Urea 	no subsidy 	no subsidy 
Which alternative would you most prefer?			

Figure 4.2: An example of a sample choice set with visual images.

4.3.1.3*Sampling design and data collection*

A multi-stage sampling procedure was used to select regions, inland valleys, and farmers. In the first stage, four regions were purposively selected by AfricaRice and the project partner institutions to capture variation in farming systems. In the second stage, a database of all inland valleys in the selected regions was provided by national research institutions, the National Centre for Agricultural Research (CNRA) and the National Agency for Rural Development (ANADER) in Côte d'Ivoire, and the Council for Scientific and Industrial Research—Soil Research Institute (CSIR-SRI) in Ghana. Four selection criteria were identified based on scientific literature, information from partners, and transect walks: physical accessibility, level of development intervention, diversification, and water management type. We used a simple multi-criteria analysis by assigning scores to each of the five 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 were selected, eight from each region that scored the highest.

For example, using the simple multi-criteria analysis formula, which is a total score (S_i) = (W1 x X1) + (W2 x X2) + (W3 x X3) +(W4 x X4), where X1, X2, X3 and X4 are the criteria and W1, W2, W3 and W4 are the weights of criterion where we gave uniform weight for each criterion. Thus, for inland valleys X and Y, it is calculated as follows: For inland valley X: S_X = (1 x 3) + (1 x 2) + (1 x 3) +(1 x 3) =11 and for inland valley Y: S_Y = (1 x 1) + (1 x 3) + (1 x 2) +(1 x 3) = 9. This way, the eight highest-scoring inland valleys in each sturdy 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 used as a sampling frame. The total households were selected randomly from that frame, proportional to the number of households per inland valley. Finally, data were collected from 801 farmers: 416 in Côte d'Ivoire and 385 in Ghana.

Survey data were collected from February to May 2021 using a household-level DCE questionnaire. We collected the data through face-to-face interviews using the data collection software package (CSPro) installed on tablets. The data were collected by trained and experienced local enumerators who know the farming systems, speak both the local language and French, and have prior experience with survey work. The enumerators were trained and supervised by a team of researchers from AfricaRice and Wageningen University in collaboration with researchers from partner institutions. We pretested the questionnaire before the actual survey. Each farmer was given the option not to participate in the survey.

4.3.2 Estimation strategy and econometric approach

The conceptual framework of the DCE method is anchored on Lancaster's economic theory of consumer choice (Lancaster, 1966). Lancaster postulated that a consumer's total utility function is separable into utilities for specific attributes of the goods rather than the goods themselves (Lancaster, 1966). The econometrics analysis of DCE data follows the behavioural framework based on McFadden's random utility theory (McFadden, 1974). McFadden explained the discrete choice in a utility-maximising framework, in which the total utility of an alternative is the sum of the utilities of each of the attribute levels plus a random component. Hence, the utility (U_{ijt}) that a farmer (i) obtains from LUD alternative (j) in a choice task (t) is composed of a deterministic part

(V_{ijt}) and an unobservable random component (ε_{ijt}). Following Hensher et al. (2015), we can describe this as:

$$U_{ijt} = V_{ijt} + \varepsilon_{ijt} \quad (4.1)$$

The deterministic part of utility is modelled as a linear function of the vector of observed attribute levels X_{ijt}. Thus, we can further specify the utility as Hensher et al. (2015).

$$U_{ijt} = \beta' \ X_{ijt} + \varepsilon_{ijt} \quad (4.2)$$

Here, X_{ijt} is the vector that contains: *i*) the alternative's score on a dummy variable indicating whether the alternative was labelled as the status quo or not, *ii*) the alternative's scores on dummy variables for the levels of Rice Productivity, On-Farm Crop Diversity, and Biodiversity, and *iii*) the amount of subsidy that comes with an alternative. Table 4.2 presents the (dummy) variables used in the model, their coding, and an indication of which levels the status quo alternative consisted of. β is a vector of regression coefficients representing: *i*) the mean utility that farmers derive from status quo labeling (relative to no status quo labeling)[6], *ii*) the mean utilities that farmers derive from the levels of Rice Productivity, On-Farm Crop Diversity, and Biodiversity (relative to the base levels), and *iii*) the mean change in utility due to a one US$ increase in yearly subsidy. It is assumed that from any given choice set, a farmer chooses the alternative that provides the highest utility to them. If we assume that ε_{ijt} is independently and identically distributed (IID), with a Gumbel distribution, the probability of choice in Equation 2 can be estimated with a multinomial model (MNL) specification(McFadden, 1974). However, the MNL model implies the independence of irrelevant alternatives assumption (IIA) (Hausman and McFadden, 1984), which states that the relative choice probabilities of any two alternatives are unaffected by the removal or inclusion of any other alternatives (Hensher et al., 2015). Moreover, this model assumes homogeneous preferences among respondents (Mzek et al., 2022); however, preferences are usually heterogeneous (Birol et al., 2006).

[6] In another common way of formulating the current model, this utility would have been captured by incorporating an alternative-specific constant in the equation for the status quo alternative and not in the equation for alternatives that are not labelled as being the status quo.

Failure to account for such heterogeneity would draw invalid conclusions about farmer preferences for appropriate management practices (e.g., LUD attributes) (Marenya et al., 2014). Hence, in a situation where the IIA assumption fails, and if one wants to account for preference heterogeneity among participants, the random parameter logit (RPL), also called mixed logit, enables unbiased estimation of individual preferences (Train and Weeks, 2005). We tested the validity of the IIA assumption using the Hausman specification test (Hausman and McFadden, 1984). It was found that the data did not support this test, as the difference matrix was not positive definite (Table 4.S2). Further analysis was thus conducted to relax the IID assumption and investigate heterogeneity in respondents' preferences. Hence, in this study, we used the RPL model. The MNL was estimated and presented as a baseline model.

4.3.2.1*The random parameter logit model*

The RPL model assumes that (some of the) utility coefficients are not constant across farmers but vary according to some distribution. In this study, we assume that the utilities that farmers derive from the levels of Rice Productivity, On-Farm Crop Diversity, and Biodiversity are normally distributed across farmers, with particular (to be estimated) means and standard deviations. For notational purposes, we split the vector. X_{ijt} into three: *i*) X_{ijt}^{Q}, the alternative's scores on the status quo dummy, *ii*) X_{ijt}^{A}, the vector that contains the alternative's scores on dummy variables for the levels of Rice Productivity, On-Farm Crop Diversity, and Biodiversity, and *iii*) X_{ijt}^{S}, the amount of subsidy that comes with an alternative. Simultaneously, we split the vector *b* into three: i) β^{Q} the mean utility that farmers derive from status quo labelling (relative to no status quo labelling), *ii*) β_i^{A} the utilities that farmer *i* derives from the levels of Rice Productivity, On-Farm Crop Diversity, and Biodiversity (relative to the base levels), and *iii*) β^{S} the mean change in utility due to a one US$ increase in yearly subsidy. β_i^{A} has index *i* since the utilities are assumed to vary across farmers. Our RPL model can thus be written as:

$$U_{ijt} = \beta^{Q}\mathrm{X}_{ijt}^{Q} + \beta_i^{A\prime}\mathrm{X}_{ijt}^{A} + \beta^{S}\mathrm{X}_{ijt}^{S} + \varepsilon_{ijt} \qquad (4.3)$$

The variation in β_i^{A} across farmers can be represented by the density function $f(\beta_i^{A}|\theta)$, where θ gives the parameters (means and standard deviations) of the normal distributions (Hensher et al., 2015). The RPL choice unconditional probability that farmer *i* selects LUD alternative *j* from choice task *t* thus becomes:

$$P_{ijt} = \int \frac{\beta^{Q}\mathrm{X}_{ijt}^{Q}+\beta_i^{A\prime}\mathrm{X}_{ijt}^{A}+\beta^{S}\mathrm{X}_{ijt}^{S}}{\sum_j \beta^{Q}\mathrm{X}_{ijt}^{Q}+\beta_i^{A\prime}\mathrm{X}_{ijt}^{A}+\beta^{S}\mathrm{X}_{ijt}^{S}} f\left(\beta_i^{A}|\theta\right)d\beta_i^{A} \quad (4.4)$$

The integral in Equation (4.4) is usually estimated through the simulation of the choice probabilities. These means and standard deviations in θ were estimated through simulated maximum likelihood using 2,000 Halton draws (Train, 2003; Hole, 2007).

4.3.2.2*The model with interaction terms*

We suspected that socio-economic characteristics were likely to have an effect on the utility of the status quo label. We, therefore, included the moderating effect of such characteristics on the utility of status quo labelling to the RPL model by adding the products of each farmer's scores, Z_i, on such characteristics with the dummy for status quo labelling as terms to the model (Aravindakshan et al., 2021). The utility function of the RPL model with the moderating effect of farmer characteristics is specified as follows:

$$U_{ijt} = \beta^{Q}\mathrm{X}_{ijt}^{Q} + \gamma^{Q\prime}Z_i\mathrm{X}_{ijt}^{Q} + \beta_i^{A\prime}\mathrm{X}_{ijt}^{A} + \beta^{S}\mathrm{X}_{ijt}^{S} + \varepsilon_{ijt} \quad (4.5)$$

Here, the vector of coefficients $\gamma^{Q\prime}$ captures the moderating effect of the farmer characteristics. This study included seven farmers and farm characteristics, location, and institutional characteristics. The choice of characteristics draws from the empirical literature on DCE preference studies (e.g., Speelman et al., 2015; Tarfasa et al., 2018). There is likely some association among these farmer characteristics, leading to potential multicollinearity issues. Multicollinearity among interaction terms can obscure the unique effects of predictors, leading to masked relationships and interpretational challenges. It also inflates standard errors, reducing the precision and reliability of coefficient estimates. We used a similar procedure employed by Sok et al. (2017) and Aravindakshan et al. (2021) to manage the potential risks of multicollinearity. This approach tests each characteristic with the status quo at a time.

Furthermore, at the beginning of the estimation, the post-estimate variance inflation factor (VIF) was run on all variables to check whether multicollinearity issues were evident in the existing model. Our estimated VIF results indicated that multicollinearity is not an issue. Besides, using the random parameter model and the model with interaction terms helps to capture both random and conditional heterogeneity (Speelman et al., 2015).

Table 4.2: Variables for attribute levels (base levels in italic)

Variables	Description
Status quo label	Alternative labelled as status quo (1 = Yes, 0 = No) – SQ
No status quo label	*Alternative not labelled as status quo*
At most 1 ton/ha	At most 1 ton/ha rice yield per cropping season (1 = Yes, 0 = Otherwise)
At least 3 tons/ha	At least 3 tons/ha rice yield per cropping season (1 = Yes, 0 = Otherwise)
2 tons/ha	*2 tons/ha rice yield – SQ*
Three crops	Potential of growing three crops (1 = Yes, 0 = Otherwise)
Five crops	Potential of growing five crops (1 = Yes, 0 = Otherwise)
Two crops	*Growing two crops – SQ*
Improve biodiversity due to environmentally friendly agricultural practices	Increased population levels of plants, trees, and animal species by 50% (1 = Yes, 0 = Otherwise)
Decline in biodiversity due to management practices that focus only on rice production	Decreased population levels of plants, trees, and animal species by 50% (1 = Yes, 0 = Otherwise)
Low biodiversity due to existing agricultural practices	*Low population levels of plants, trees, and animal species - SQ*
Subsidy	One-time annual incentive payment in US$ (0, 65, 130, 195, 255) – *SQ comes with 0 subsidy*

4.3.2.3 *Willingness to accept*

In this study, a subsidy is used to encourage land use management practices with certain attributes. Consequently, a farmer would accept a lower subsidy only in exchange for an attribute level that she prefers compared to the baseline. Accordingly, a positive value for the average marginal rate of substitution between a given attribute and the subsidy implies that farmers, on average, dislike the level of the attribute compared to the baseline and hence would require a larger subsidy, the higher the WTA, the stronger the preference against that attribute level. A negative marginal rate of substitution (negative WTA) implies a higher preference for the attribute level instead of the baseline, in which case a reduction in the subsidy is acceptable. We calculated marginal WTA values and their 95% confidence interval based on the estimated parameters of the basic RPL model using the Delta method with 1,000 simulations, a common approach in DCE modelling (e.g., Schulz et al., 2013). Assuming a linearly specified utility function for a subsidy, the marginal WTA for a particular attribute level (in comparison to the baseline) is computed following Train and Weeks (2005) as follows:

$$\widehat{WTA} = -\frac{\widehat{\beta}_l'}{\widehat{\beta}_s} \qquad (4.6)$$

where β_l' and β_s are the coefficients of the LUD non-cost and subsidy attribute levels, respectively. In this study, we analysed the data using R software 4.1.0 (R Core Team, 2017) and the 'mlogit' package (Croissant, 2020).

4.4 Results and Discussion

4.4.1 Descriptive statistics of respondent characteristics

We present the descriptive statistics of farmers' characteristics in Table 4.3. About 87 % of the respondent farmers were male household heads, and the average household head's age was about 46 years. On average, farmers reported more than 20 years of farming experience. The average family size was nine people. Farmers' education levels were generally low, with 66 % having primary and lower education levels, and about 37% of the household heads were uneducated. The average land area cultivated by the sample households was 2.6 hectares. Only 10 % and 30 % of the sample households had access to credit and off-farm income-generating activities, respectively. This result implies that access to credit and involvement in off-farm income-generating activities are low. The result also revealed that about 67% of the sample farmers reported having access to extension services. Almost 90 % of the farmers reported having market access; on average, respondents reported that they could travel the distance from their homes to the nearby market centres in about one hour.

Before applying the econometric models, those surveys that showed a constant preference for the SQ alternative were analysed. In these cases, only 2.52% were not interested in the alternative LUD attributes and consistently chose the status quo. As expected, an equal distribution of choices is found between the two hypothetical LUD attributes presented to a respondent. The first LUD alternative is chosen in 49.51% of the choice occasions, and the second in 47.97% of the cases, confirming the nonexistence of selection bias in the hypothetical contract alternatives due to design errors (Tarfasa et al., 2018).

Table 4.3: Summary statistics of sample farmers (N=801)

Variable	Unit/Coding	Mean / Proportion (Standard Deviation)
Age	Years	46.49 (11.76)
Gender	1= Male, 0 = Otherwise	0.87 (0.34)
Education	1= Primary and lower, 0 = Otherwise	0.66 (0.47)
Household size	Number	9.14 (4.91)
Access to credit	1= Yes, 0 = No	0.09 (0.29)
Extension access	1= Yes, 0 = No	0.67 (0.47)
Farm experience	Years	20.55 (12.13)
Access off-farm income	1= Yes, 0 = No	0.31 (0.46)
Access to market	1= Yes, 0 = No	0.90 (0.30)
Distance to market	Minutes	59.13 (95.54)
Land cultivated	Hectares	2.59 (1.76)
At most 1 ton/ha	At most 1 ton/ha rice yield per cropping season (1 = Yes, 0 = Otherwise)	0.15 (0.36)
At least 3 tons/ha	At least 3 tons/ha rice yield per cropping season (1 = Yes, 0 = Otherwise)	0.59 (0.49)
2 tons/ha	2 tons/ha rice yield per cropping season (1 = Yes, 0 = Otherwise)	0.26 (0.44)
Three crops	Potential of growing three crops (1 = Yes, 0 = Otherwise)	0.22 (0.41)
Five crops	Potential of growing five crops (1 = Yes, 0 = Otherwise)	0.56 (0.50)
Two crops	Potential of growing two crops (1 =Yes, 0 = Otherwise)	0.21 (0.42)
Improve biodiversity due to environmentally friendly agricultural practices	Increased population levels of plants, trees, and animal species by 50% (1= Yes, 0 = Otherwise)	0.29 (0.46)
Decline in biodiversity due to management practices that focus only on rice production	Decreased population levels of plants, trees, and animal species by 50% (1= Yes, 0 = Otherwise)	0.19 (0.39)
Low biodiversity due to existing agricultural practices	Low population levels of plants, trees, and animal species at the status quo level (1= Yes, 0 =Otherwise)	0.52 (0.50)
Subsidy	One-time annual incentive payment in US$	143.39 (176.39)

4.4.2 Results of main-effects MNL and RPL Model

4.4.2.1 *Aggregate-level point estimates*

Table 4.4 presents the basic MNL and RPL model estimation results. Both models fit the data well. Based on Hensher et al. (2015), the value of McFadden Pseudo-R2 of both models is within the range for a good fit model (0.2-0.4). The value of McFadden Pseudo-R2, the Akaike information criteria (AIC), and the Bayesian information criteria (BIC) show that the explanatory power of the RPL model is higher than the MNL model.

The result of the RPL model presents the estimated mean and standard deviations of the attribute-level utilities, together with their standard errors. The results indicate that all the marginal utilities of attribute levels are significant, except for the increasing level

of biodiversity conditions. A positive significant mean marginal utility indicates a positive preference and increases in utilities compared to the base level. The opposite holds for significant negative mean marginal utilities. The signs of all the attribute-level marginal utilities are as expected a priori. As expected, the marginal utility of subsidy is positive, meaning that a higher subsidy payment increases the utility and the probability of choosing a particular alternative.

Ceteris paribus, the results demonstrate that farmers prefer diversification of five crops and increased rice productivity. However, farmers have negative preferences for reduced biodiversity levels (Table 4.4). The preference for economic and ecological attributes reveals that farmers do see positive benefits from the sustainable management of the inland valleys. Regarding rice productivity attributes, compared to the status quo (2 tons/ha), farmers reported higher preferences for at least three tons/ha of rice productivity. The result implies that, on average, most farmers want to sustainably enhance rice production to meet their families' growing food demands. The result of this study substantiates the findings of Ortega et al. (2016) and Owusu Coffie et al. (2016), who found that higher utility is associated with a higher yield.

Regarding crop diversity, farmers faced a choice between diversification packages that included two, three, or five different crops. Farmers have a significant preference for higher crop diversity, with diversification packages including five crops being, on average, the most preferred choice. The results indicate that farmers have a strong preference for higher crop diversity, with five-crop diversification packages being the most preferred choice.

This preference may reflect an understanding of the benefits of diversification, such as yield stability, beyond the inclusion of only two crops. By diversifying crop production, farmers gain some assurance that they can have something to eat even in the event of crop failure, food price shocks, or lack of food in local markets. Moreover, in inland valleys where some crops are not edible until processed (e.g., milling), they may be selling some of the crops to purchase other foodstuffs, especially given that our sample indicated high market access (Table 4.3). This result aligns with Mzyece and Ng'ombe's (2021) and Alcon et al. (2020) that crop diversification builds resilience in farming systems as adaptive management for environmental change.

The result also aligns with the literature, which states that farmers diversify their economic activities to improve their risk management capacity (Barrett et al., 2001; Lin, 2011), and diversified systems often incorporate regionally appropriate crops suited to climate resilience and market opportunities (Kerr et al., 2007; Altieri and Nicholls, 2017).

Table 4.4: Multinomial (MNL) and random parameter logit (RPL) estimates for LUD attributes.

Attribute(s) (levels)	MNL model	RPL model	Prop. Neg.[c]
	Mean (SE)	Mean (SE)	
At most 1 ton/ha (reduction from SQ level)	-0.43*** (0.04)	-0.62*** (0.06)	-
At least 3 tons/ha (increase from SQ level)	0.38*** (0.05)	0.39*** (0.05)	-
Three crops (increase from SQ level)	0.16*** (0.06)	0.17*** (0.07)	-
Five crops (increase from SQ level)	0.52*** (0.05)	0.83*** (0.08)	-
Improve biodiversity due to EFAP (increase from SQ level)	0.08 (0.10)	0.10 (0.14)	-
Decline biodiversity (reduction from SQ level)	-0.25*** (0.05)	-0.21*** (0.07)	-
Status quo label	-2.33*** (0.11)	-2.38*** (0.14)	-
Subsidy	0.003*** (0.0002)	0.004*** (0.0003)	-
Attribute(s) (levels)	MNL model	RPL model	Prop. Neg.[c]
	Standard deviation (SE)	Standard deviation (SE)	
At most 1 ton/ha (reduction from SQ level)	-	0.93 *** 0.14)	0.75
At least 3 tons/ha (increase from SQ level)	-	1.26*** (0.18)	0.48
Three crops (increase from SQ level)	-	0.19 (0.47)	0.18
Five crops (increase from SQ level)	-	0.74*** (0.16)	0.13
Improve biodiversity due to EFAP (increase from SQ level)	-	1.68*** (0.17)	0.47
Decline biodiversity (reduction from SQ level)	-	0.02*** (1.38)	0.90
Model fit statistics			
Log-Likelihood	-2809.4	-2713.72	-
Degrees of freedom	8	14	-
McFadden's pseudo-R^2	0.34	0.38	-
AIC/N	1.41	1.33	-
BIC/N	1.43	1.35	-

Notes: $N_{respondents}$= 801, $N_{choice\ sets}$= 4,005. [c] The proportion of farmers with negative utility relative to the base level. Calculated using Φ(-coef['β'''] / coef(['δ_i']) (Hole, 2007). SE is standard error. *** denotes significance at the 1% level.

The estimates for biodiversity indicate that farmers have negative preferences for reduced biodiversity levels and environmental conditions relative to the status quo levels. This negative preference may suggest that farmers believe that the current quality of biodiversity cannot be reduced much further without impacting their livelihoods. We also find a positive, albeit non-significant, preference for increased biodiversity. Taken together, we interpret this as a strong indication that inland valley farmers are content with the current levels of biodiversity. Farmers in these inland valleys are highly

dependent on biodiversity for hunting, fishing, and wild foods for their daily livelihoods, but they are very capable of understanding the trade-offs involved in managing biodiversity in these valleys.

On the one hand, it is clear that farmers care for biodiversity and do not want to see it reduced. Similar results include, for example, farmers in Togo and Benin who contributed to biodiversity conservation through the community forest reserve and gardens in the inland valleys (Rodenburg et al., 2012). A similar result was found in Tanzania wetlands (Speelman et al., 2015; Adhikari et al., 2017). On the other hand, increasing the amount of biodiversity is costly; nonetheless, if it implies sacrificing productivity. Farmers in our sample appear not to be willing to do such a thing. Although the marginal utility of increasing biodiversity with environmentally friendly agricultural practices is insignificant, the standard deviation of this estimate is significant. This does imply that there is significant heterogeneity in preferences for additional biodiversity, with subjects showing both negative and positive preferences.

4.4.2.2*Farmers' preference heterogeneity*

In the RPL model (Table 4.4), all the marginal utilities' standard deviations, except for the three crops' diversity, are highly significant, indicating that there are indeed heterogeneous preferences for the attribute-level marginal utilities among farmers. The relative magnitudes of the standard deviations of the coefficients also indicate considerable variation in preferences. This implies that some farmers might have reverse or opposite preferences for the attribute levels (Broch and Vedel, 2012). For example, 48% and 13% of the farmers reported negative preferences for 3 tons/ha of rice productivity and five crop diversifications, respectively. These results further indicate that these farmers would require an additional subsidy to increase rice productivity from 2 tons/ha to 3 tons/ha and diversify from two crops to five crops.

4.4.2.3 *Willingness to Accept Estimates*

Table 4.5 presents the results of the marginal WTA estimates and their 95% confidence intervals. Ceteris paribus, getting farmers to reduce rice productivity by at least 1 ton/ha as an inland valley conservation requirement would, on average, require an extra subsidy payment of approximately $142.29/ha/year. Otherwise, farmers would prefer to stay with the status quo (2 tons/ha) category. However, farmers are happy to accept a lower subsidy (reduced by the equivalent of $102.19/ha/year of fertiliser) if rice production is allowed to increase from 2 tons/ha to 3 tons/ha. Farmers show a clear preference for increased crop diversity and are willing to accept lower subsidies (reduced by $190.34/ha/year) if crop diversity is increased to five instead of the current status quo level of two crops. Similarly, farmers are willing to accept a $40.30/ha/year less subsidy for three-crop diversification than for two crops.

Regarding biodiversity, although a decrease in biodiversity is acceptable only in exchange for increased subsidisation (by $48.15/ha/year to accept 50 % lower levels of biodiversity compared to their current situation), farmers do not have a preference for increased biodiversity, especially not so if it entails a lower subsidy. Notably, Table 5 shows considerable heterogeneity in this result.

Table 4.5: Willingness-to-accept (WTA) estimates (95% confidence interval).

Attributes	WTA (USD PPP) ha^{-1} $year^{-1}$	Lower bound WTA (USD PPP) ha^{-1} $year^{-1}$	Upper bound WTA (USD PPP) ha^{-1} $year^{-1}$
At least 3 tons/ha	-102.19	-193.47	-95.04
At most 1 ton/ha	142.29	107.45	177.04
Three crops	-40.30	-72.16	-8.43
Five crops	-190.34	-230.55	-150.13
Improve biodiversity due to EFAP	-23.12	-91.25	45.01
Decline biodiversity	48.15	16.29	80.01

Note: PPP- purchasing power parity. A positive WTA estimate means that increased subsidisation is needed to convince farmers to accept the attribute level. A negative WTA estimate means that farmers prefer the level of the attribute so that a reduce subsidy is acceptable.

4.4.3 Estimations of the Interaction Model

As an extension of the basic model, the interaction terms depict the characteristics of the farmers who chose the status quo in the DCE. The results of the interaction model are presented in Table 6. The variables of farmer and farm characteristics include age, gender, level of education, access to credit, access to market, land cultivated, and location dummy (country) are included in the interaction model. The estimations of the attribute variables

were consistent with the basic models in Table 4.4, indicating that the estimations are robust (Schaafsma et al., 2019; Chèze et al., 2020).

The negative and significant effect of age on the utility of status quo labelling (Table 4.6) shows that older farmers have a lower possibility of adopting the alternative LUD attributes, implying they are more likely to go for the status quo. The interaction between the education level of the household and status quo labelling is positive and significant, implying that relatively educated farm households are more likely to choose the proposed LUD attributes compared to their less educated counterparts. The interaction term between the status quo labelling and the farmer's land cultivated was found to be significant and positive, which may imply that households with relatively large landholdings are more interested in entering to choose the alternative LUD attributes. This indicates that the land they cultivate significantly influences farmers' land use decisions.

The results of the interaction model show that compared to the RPL model without interaction, the value of the log-likelihood function is relatively reduced further, implying that improvement in the model fit is achieved with the inclusion of respondent characteristics in the RPL model.

Table **4.6**: RPL model estimates – with interactions with individual characteristics.

Attributes	Mean (SE)	SD (SE)
At least 3 tons/ha	0.32*** (0.04)	1.09***(0.16)
At most 1 ton/ha	-0.57***(0.06)	0.80***(0.12)
Three crops	0.16***(0.07)	0.04(0.23)
Five crops	0.77***(0.07)	0.59***(0.14)
Improve biodiversity due to EFAP	0.03(0.13)	1.51***(0.17)
Decline biodiversity	-0.21***(0.06)	0.08(0.24)
Status quo label	-2.11*** (0.79)	-
Subsidy	0.004*** (0.0003)	-
Interaction with covariates		
Status quo label x Age	-0.03***(0.01)	-
Status quo label x Male	-0.35 (0.32)	-
Status quo label x Education	0.51***(0.29)	-
Status quo label x Access to credit	-0.62 (0.52)	-
Status quo label x Access to market	0.56 (0.42)	-
Status quo label x Land cultivated	0.03***(0.01)	-
Status quo label x Côte d'Ivoire	0.43(0.27)	-
Model fit statistics		
Log-Likelihood	-2708.1	-
McFadden's pseudo-R^2	0.38	-

*** denote significance at the 1% level.

4.5 Conclusion and policy implications

Inland valley wetlands provide crop and non-crop benefits on which the livelihoods of many farmers depend. Government policy in the inland valleys in West Africa has focused on increasing the use of this landscape for rice production by intensifying existing cropland and expanding the area used for rice. However, these policies do not account for farmers' preferences, who could be interested in multiple other attributes of inland valleys. They have also historically failed to assess farmers' preferences for alternative LUD attributes adequately. The resulting indiscriminate use of inland valleys for the sole purpose of rice production leads to the degradation of inland valleys' biodiversity. It also makes the sustainability of crop production ineffective and threatens other non-crop benefits of the inland valleys. Besides, ignoring heterogeneity oversimplifies farmers' preferences, leading to generalised policy recommendations that may not be effective across varying farmer contexts. Thus, in response to these notable gaps, we used a DCE to examine the heterogeneity of farmers' preferences and delve into the determinants of preference heterogeneity for LUD attributes.

In general, we obtained three main results. First, farmers clearly prefer development alternatives that enhance sustainable agroecological systems. Farmers prefer diversified production systems embedded in biodiversity-rich areas. Compared with the current inland valley uses, farmers reported strong preferences for the alternative LUD attributes that imply increased diversification in terms of the number of crops on their land. Second, we find that farmers have a clear preference for the current level of biodiversity. This preference is expressed in two ways: an increased fertiliser subsidy would be required if biodiversity is to decline. At the same time, farmers, on average, do not prefer increased biodiversity.

Although there is significant heterogeneity among farmers regarding their preference for more or less biodiversity, the average farmer unequivocally prefers the status quo. This finding appears to contradict previous findings in the literature that farmers would be willing to make the necessary changes in their management practices to protect and sustainably manage biodiversity if a subsidy is in place to cover short-term costs (e.g., Jaeck and Lifran, 2013; Greiner, 2015). We instead argue that farmers do have a preference for biodiversity and are willing to invest in it, but they also have a personal

insight into how much biodiversity is good for them. In our case, that level seems to be the status quo.

This finding highlights the need to recognise the economic realities faced by farmers and the importance of taking farmer preferences into account in the design of programs that promote agricultural practices that contribute to biodiversity conservation in the long run. We do recognise that our result takes the level of knowledge and information of farmers as given at baseline and does not attempt to change it to produce a better understanding of the benefits of biodiversity and associated conservation measures. One could then argue that to promote increased biodiversity levels in these inland valleys, farmers need more information about the contribution of biodiversity and biodiversity conservation measures to farm productivity and profits.

Finally, the findings reveal significant differences among the farm household factors that drive farmers' preferences for attributes of LUD alternatives. Altogether, this study's findings identified farmers' readiness for change in the inland valleys where they live and work, suggesting that farmers may be key actors in the sustainable development of these socially, economically, and ecologically significant landscapes.

Our findings carry several policy implications. First, the result showed that farmers' strong preference for five-crop diversification packages, indicating their recognition of the benefits of diversification. Thus, we recommend that policymakers consider and work on diversifying crops as a key livelihood strategy. Especially in the face of climate change, which poses a threat to many farmers' food security and livelihoods (e.g., Lipper et al., 2014), the promotion of crop diversification strategies is beneficial.

Farmers' preference for diversification allows policymakers to promote the adoption and use of system-appropriate crops that support environmental, social, and economic goals. For instance, given the projections of future climate models, policymakers can leverage farmers' existing preference for crop diversification to introduce crops that reduce climate risk while supporting economic goals. In this sense, it is important to consider indigenous and locally adapted crops and landrace varieties that have a national identity, heritage, and sense of place, which often form a complex part of the culture and diets of the people. The literature has historically undervalued such socio-cultural forms of production, but farmers' social and cultural lives drive their decisions just as much as their economic lives.

Second, inland valley farmers expressed a clear preference to maintain the current level of biodiversity. More than that, farmers believe that reduced levels of biodiversity beyond the current level might negatively impact their livelihood, hence the need for increased fertiliser subsidies. In other words, farmers do have an understanding of what is the preferred level of biodiversity in these inland valleys and the implications of changes thereof on their livelihoods. Any attempt at changing that level would require improved information on the current status of biodiversity in these inland valleys and its impact on farmer's livelihoods. Moreover, finding an optimal balance between the economic needs of farmers and the conservation of biodiversity is crucial for the long-term sustainability of these ecosystems.

Third, inland valley farmers show preferences for the different LUD attributes. This suggests that policies aimed at LUD could be designed with these preferences in mind. One key implication is that it is critical to involve farmers in the inland valleys in the development and management of land use practices, elicit their preferences, and streamline their interest in improving their use of inland valleys. Ultimately, the objectives of designing policies and developing technological innovations and interventions should be to encourage farmers to select and adapt infrastructure, technologies, and practices suited to the environment and relevant to their needs. Policymakers, researchers, and development staff, among others, need to think about how to enable farmers to make their own decisions according to their preferences.

Finally, we do recognise that our results are coming from a representative sample of farmers in inland valleys in four regions of two West African countries. West Africa's rice-producing inland valleys have unique dynamics and challenges, and it is essential to recognise that these features do shape agricultural practices. Extrapolating these findings directly to other regions without considering these contextual nuances may lead to inaccurate interpretations and ineffective interventions. Furthermore, another limitation of this study is the possibility of attribute non-attendance (ANA), where farmers might disregard certain attributes.

Although we carefully selected attributes and levels pertinent to smallholder farmers, differentiating between artificial and intentional ANA remains difficult. ANA can stem from methodological restrictions or genuine disinterest, complicating determining its exact impact. Future research should tackle ANA. Besides, due to the absence of reliable

and transparent data on land tenure, this study did not assess the effect of land tenure on farmer preferences for LUD attributes. Future research should consider integrating land tenure variables to better understand their role in shaping farmers' preferences for LUD. By acknowledging the limitations and context-specific nature of this study's findings, we can foster a more nuanced and comprehensive understanding of rice production practices worldwide. Thus, further work in other inland valley systems could build upon this study to contribute to broader inland valley policy and land use discussions.

Supplementary material Chapter 4

Table 4.S1: Detailed description of attributes and attribute levels

Attribute	Attribute definition	Levels	Level description
Rice productivity (RP)	The average yield of rice production in tons per hectare (ton/ha).	2 tons/ha (SQ)[7] 	2 ton/ha average rice yield
		At least 3 tons/ha ≥ 	Rice yield, on average, increased by 50% and above with the technical support from AfricaRice and extension services of the national systems.
		At most 1 ton/ha ⩽ 	Rice yield, on average, decreased by 50% and less because of the biodiversity conservation measures for sustainable crop production in the future (e.g., use of your piece of land for community-managed plant garden, forest reserve, preserving trees and useful species during land preparation).
On-farm crop diversity (CD)	The potential number of crops grown on the farm.	Two crops (SQ) 	Grow two crops to reduce dependency on rice production.
		Three crops 	Grow three crops to decrease the risk of monocropping and dependency on a few crops.
		Five crops 	Grow five crops to reduce the risks associated with price fluctuations, insects, pests, and disease. Diversify diet and conservation of natural resources.
Biodiversity resulting from alternative cultivation practices (BD)	Population-level of different plants, trees, and animal species in and around the inland valleys	Low (SQ) 	The numbers of native trees, wild animals, and other different plant and animal species are low, with a minimal number of plants, trees, and animal species compared to the past. This is because you are not working on biodiversity conservation measures.
		50% improvement and environmentally friendly agricultural practice training 	The number of native trees, wild animals, and other plant and animal species will improve and increase by half from the current level. However, it is required from you to implement more biodiversity conservation measures (e.g., use of your piece of land for a community-managed plant

[7] SQ - stands for the status quo, which refers to most farmers' current levels for each attribute.

			garden, forest reserve, preserving trees and useful species during land preparation). As a result, you may get more non-crop benefits from the inland valleys and sustainable crop production in the future.	
		50 % decline due to management practices that focus only on rice production 	The number of native trees, wild animals, and other plant and animal species will worsen and decline by half. This is because you will focus on rice production and the unsustainable exploitation of inland valley resources.	
Subsidy (SD)[a8]	The government provides a one-time fertiliser subsidy per ha annually if the conservation measures are applied to a hectare.	no fertiliser subsidy (SQ) 	0$ year^{-1}≈ 0GHS 0$ year^{-1}≈ 0 CFA	You will not get fertiliser subsidies (0GHS) or (0CFA).
		50kg NPK + 50kg Urea 	65$ year^{-1}≈402GHS 65$ year^{-1}≈37, 800 CFA	You will receive a subsidy of X kg of NPK + Y kg Urea fertiliser from your government annually applied to one hectare. This is an equivalent of approximately (W GHS) or (w CFA) (equivalent to P $).
		100kg NPK + 50kg Urea 	130$ year^{-1}≈ 603GHS 130$ year^{-1}≈ 56, 700 CFA	
		150kg NPK + 100kg Urea 	195$ year-1≈ 1005GHS 195$ year^{-1}≈ 94, 500 CFA	
		200kg NPK + 100kg Urea 	255$ year^{-1}≈ 1205GHS 255$ year^{-1}≈ 113,400 CFA	

[8] The subsidy attribute is in-kind fertilizer subsidy, and its equivalent monetary values were also presented. Because the survey was conducted in two different countries, the currencies are also different. Thus, we presented the respondent in their respective currency to capture the difference. Finally, we converted it into purchasing power parity (PPP) for the willingness to accept analysis. GHS = Ghanaian Cedi (the official currency of Ghana) and CFA = Communaute Financiere Africaine (the official currency of Cote d'Ivoire). During the survey period (February – May 2021), the official exchange rate was: 1USD = 5.7 GHS and 1USD = 540 CFA.

Box 4.S1: Explanation of the choice task to farmers

Instruction to the interviewer

Read the scenario described below to the respondent farm households and describe the printed and laminated illustrative visual images of the choice sets. Please ensure that the respondent farm households give attention to (and understand) the description before proceeding to the following questions.

Explanation to the respondent

We are presenting to you three possible inland valley use and development alternatives. You should always choose only one that you find most preferred and attractive out of these alternatives. Please also note that although this is only a survey, the options presented here are realistic and could apply to your inland Valley production situation in the future. Therefore, we kindly ask you to carefully understand and consider the available alternatives and choose if this is a real inland valley use and development option. Your preference is essential to better understand smallholder farmers' preferences to make the use and development of inland valleys sustainable. Any future options will be designed based on the smallholder farmers' preferences in the inland valleys. Moreover, the result obtained from this study can help to make some general recommendations about how to improve and sustainably use and develop the inland valleys in an environment-friendly manner.

Suppose in the choice set, you have three inland valleys use and development alternatives you can choose from (Table 2 in the main text).

If you choose alternative 1, you will get an average rice yield of less than or equal to 1 ton/ha per cropping season. This means your rice yield declined by at least half of what you currently produce. However, you have the potential to grow three crops, including rice, per cropping season, which helps to reduce your risk of depending only on one crop. Moreover, the number of native trees, wild animals, and other plant and animal species will improve and increase by half from the current level. However, it is required from you to implement more biodiversity conservation measures (e.g., use of your piece of land for a community-managed plant garden, forest reserve, preserving trees and useful species during land preparation). As a result, you may get more non-crop benefits from the inland valleys and sustainable crop production in the future. If you agree to choose this alternative, you will receive a subsidy of 200kg NPK + 100kg Urea fertilizer from your government annually applied to one hectare. This is an equivalent of approximately (1205GHS) or (94,500CFA) or (255$).

If you choose alternative 2, you will get an average rice yield greater than or equal to 3 tons/ha of rice per cropping season. This means that your rice yield increased by at least half of what you are currently producing because of the technical support from AfricaRice and extension services from the national systems. Moreover, growing two crops, including rice per cropping season, remains the same. However, the number of native trees, wild animals, and other plant and animal species will worsen and decline by half. This is because you will focus on rice production and the unsustainable exploitation of inland valley resources. As a result, your non-crop benefit declined, and the rice yield declined over time. If you agree to choose this alternative, you will not get any fertilizer subsidy (0GHS) or (0CFA) or (0$).

The third alternative is the status quo or the current scenario alternative. If you select the status-quo alternative, you will get an average rice yield of 2 tons/ha per cropping season. Moreover, growing two crops, including rice per cropping season, remains the same. However, the number of native trees, wild animals, and other different plant and animal species are low, with a minimal number of plants, trees, and animal species compared to the past. This is because you are not working on biodiversity conservation measures. Instead, you are using the resources unsustainably compared to the past. If you agree to choose this alternative, you will not get any fertilizer subsidy (0GHS) or (0CFA) or (0$). What would we like to know from you is which of these three alternatives would you prefer most?

Table 4.S2: Hausman–McFadden test of independence of irrelevant alternatives

Alternative dropped	$\chi 2$ - statistic	Degrees of freedom	p-value
Alternative 1	177.55	7	<.001***
Alternative 2	165.50	7	<.001***
Status quo	575.35	7	<.001***

Note: *** denotes significance levels at 1%.

Chapter 5
The Contribution of Wild Foods to Household Food Security: Evidence from the Inland Valley Wetlands of Côte d'Ivoire and Ghana

This chapter is based on the manuscript Alemayehu, T., Alpizar, F., & Giller, K. E. (2026). The Contribution of Wild Food to Household Food Security: Evidence from the Inland Valley Wetland of Cote d'Ivoire and Ghana.

Abstract

Wild foods play an important, yet often overlooked, role in supporting households' food security and income. Although past research has measured household food availability, empirical evidence on the specific contribution of wild foods remains limited. This study addresses this gap by assessing the extent of wild food collection, quantifying its monetary value for food security and income, and identifying wild food collection determinants using data from 786 farmers in the inland valley wetlands of Côte d'Ivoire and Ghana. We measured household food security in kilocalories per male adult equivalent per day (kcal MAE^{-1} day^{-1}) and income (USD PPP) and valued wild foods using a replacement cost method for consumption and market prices for sales. A probit model was used to identify determinants. The results revealed that 60% of the farmers collected wild foods. For the poorest income quintile, wild foods contribute 79.2% of total cash income, equivalent to 825.89 USD PPP MAE-1 annually. Their annual contribution to household food security ranged from 217.84-470.84 USD PPP MAE-1, or 576-2346 kcal MAE^{-1} day^{-1}. Excluding this contribution from food availability assessments increased food insecurity by 7-15%. Age, food insecurity, market access, and distance to inland valleys significantly influence wild food collection. Interestingly, wild food collectors show greater awareness of provisioning ecosystem services. The findings of this Côte d'Ivoire and Ghana case study highlight the potential of wild foods to improve household food security and reduce poverty. Integrating wild foods into national food policies, improving ecosystem management, and designing targeted interventions would enhance food security and poverty reduction.

Keywords: Wild foods, Food security; Inland valleys; Ecosystem services; Côte d'Ivoire; Ghana.

5.1 Introduction

Food security, defined as the fundamental right of people to access sufficient, safe, and nutritious food through production and/or purchase without harming the social and biophysical environment, remains a pressing global problem. In West Africa, this problem is particularly severe, with 62% of the population experiencing moderate or severe food insecurity (FAO, 2024).

Approximately one in seven people worldwide experience food insecurity, with smallholder farmers in sub-Saharan Africa facing the highest prevalence (Sibhatu et al., 2015; Frelat et al., 2016; Hickey et al., 2016; Giller et al., 2021). This chronic and persistent crisis, driven by rapid population growth, climate variability, and unsustainable agricultural practices, raises a critical question: can wild foods play a greater role in enhancing food security and resilience? (Foley et al., 2011; Hickey et al., 2016). For example, meeting the food demand of a growing global population will require at least a 70% increase in food production from 2007 levels by 2050 (Huang et al., 2011; Hickey et al., 2016). Nevertheless, strategies to increase food availability must also consider biodiversity conservation and sustainability to minimise the ecological footprint of food production and prevent further environmental degradation (Phalan et al., 2011; Smith, 2013; Hickey et al., 2016).

This study answers three key research questions: (1) To what extent do the consumption and sale of wild food contribute to household food security (kilocalories) and poverty reduction (income), in the inland valley wetlands of Côte d'Ivoire and Ghana? (2) What are the major determinants influencing the collection of wild food among farmers? (3) What is the relationship between wild food collection and farmers' awareness of provisioning ecosystem services?

By analysing household-level survey data from four regions across two countries, this study provides empirical evidence to inform food security policies and promote sustainable resource management, and strategies for integrating biodiversity into agricultural development. Understanding the role of wild foods can contribute to more comprehensive and inclusive food security frameworks, providing an empirical basis for targeted programs and policies, such as inland valley management, conservation incentives, and household-level food security interventions, which promote both environmental sustainability and livelihoods.

A focus on wild foods is especially relevant given that, in addition to food insecurity, sub-Saharan Africa faces a significant problem with malnutrition, with approximately 277 million people undernourished, including 70 million in West Africa (FAO, 2024). Micronutrient deficiencies have profound health consequences, impairing children's physical and mental development, reducing labour productivity, and incurring substantial economic costs (Sibhatu et al., 2015; Koppmair et al., 2017). Yet, food security strategies often focus on staple food production and market access, while overlooking alternative food sources such as wild foods, which can play an essential role in increasing food availability, dietary energy, dietary diversity, and resilience (Sunderland, 2011; Shumsky et al., 2014).

In West Africa, the inland valley wetlands of Côte d'Ivoire and Ghana are biodiversity hotspots that support the collection of a variety of wild foods. Wild foods provide essential nutrients and income for smallholder farmers, serving as a safety net for their livelihoods and providing resilience during periods of agricultural shortfalls (Brashares et al., 2011). According to (Brashares et al., 2011), up to one billion people supplement their diets and generate income from wild foods. Unlike many crops, wild foods often exhibit greater resilience to climate change and can support adaptation strategies for smallholder farmers (Chivandi et al., 2015; Paumgarten et al., 2018). Despite these benefits, quantified evidence on the contribution of wild foods to household food security and income remains limited.

In many studies, food availability (FA) is widely used as a measure of household food security. It is often quantified in kilocalories per male adult equivalent per day (kcal MAE^{-1} day^{-1}), emphasising energy from key livelihood activities such as on-farm production, food purchased, and income from on-farm activities, and to analyse the relative contribution of each of these livelihood activities to overall FA and poverty reduction (e.g., Hammond et al., 2017; Lopez-Ridaura et al., 2018).

However, these studies have largely neglected the contribution of wild foods, limiting their inclusion in food security policy and biodiversity conservation. Moreover, it is necessary to identify the socio-economic, institutional, and seasonal factors that influence wild food collection. Nevertheless, such determinants remain underexplored. In addition, the link between wild food collection and provisioning ecosystem services provided by inland valleys remains unexplored, even though such awareness could shape sustainable

resource use practices and support biodiversity conservation. Addressing these gaps is key for informing decision-makers about the potential benefits of wild foods to food security and for balancing food security objectives with biodiversity conservation (Sunderland, 2011; Becquey et al., 2012; Hickey et al., 2016).

5.2 Methods

5.2.1 Study areas

This study was part of a larger research project coordinated by AfricaRice to study food and nutrition security for smallholder farmers in Côte d'Ivoire and Ghana. These are the two West African countries where the project was implemented, and within which this study was conducted. Agriculture is the primary source of occupation and livelihood for most of the working population in these two countries. These countries have large inland valley wetlands (Diagne et al., 2013), which harbour diverse wild edible species and support agriculture, making them an ideal context for quantifying the contribution of wild food collection to food security.

Data were collected in two regions in Côte d'Ivoire (Bouaké and Gagnoa) and two regions in Ghana (Ahafo Ano North and Ahafo Ano South). Figure 5.1 presents a map of the study areas. These regions belong to two contrasting agroecological zones (AEZs), namely humid and subhumid zones, highlighting the diversity of the study areas. These contrasting AEZs provide diverse environmental and socio-economic contexts for the study. The rainfall pattern is unimodal in subhumid AEZs and bimodal in the humid AEZs (Ghana Statistical Services, 2014; National Institute Statistics, 2014). Additionally, inland valleys offer crucial ecosystem services for the well-being of smallholder farmers (Alemayehu et al., 2022).

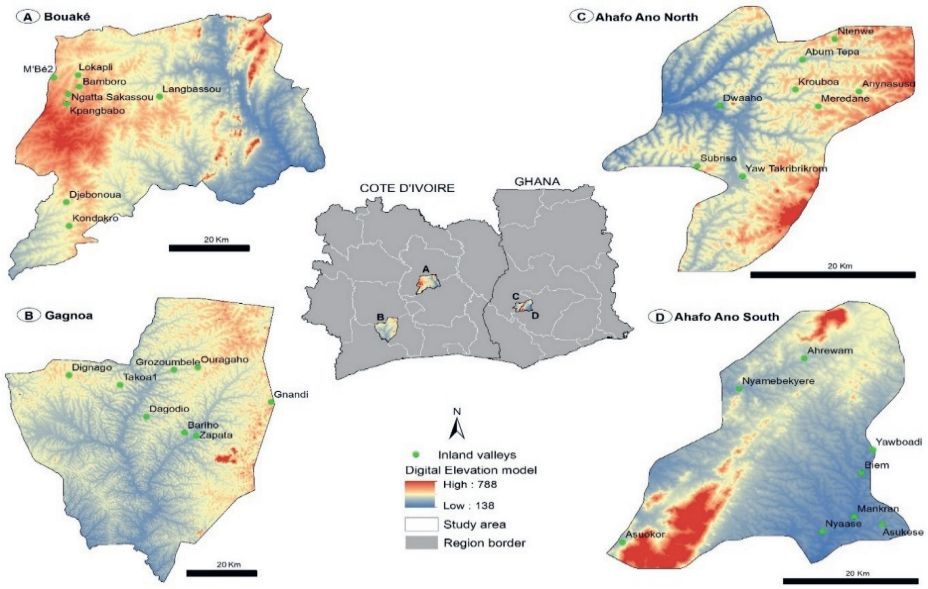


Figure 5.1 Map of the study area

5.2.2 Data sources

The study used data from the Rural Household Multi-Indicator Survey (RHoMIS) tool (http://www.rhomis.org), supplemented with additional questions specific to the study context. RHoMIS data are collected using a standardised survey tool that has been in use since 2015 (Tacconi et al., 2023). The RHoMIS comprises several modules designed to gather information and calculate indicators related to the socio-economic status of rural households, farm production, livelihood strategies, wild foods, and food security (Hammond et al., 2017; van Wijk et al., 2020; Tacconi et al., 2023). The main RHoMIS household indicators and their units used in this study are described in Table 5.1. The use of RHoMIS data allows the analysis of household performance in terms of food security from various sources on the basis of the characteristics of their farms.

5.2.3 Sampling and data collection

A multi-stage sampling procedure was used to select regions, inland valleys, and households. In the first stage, four regions were purposively selected to capture variation in farming systems. Efforts were made to include inland valleys covering a broad range of ecological and socio-economic conditions. In the second stage, a database of all inland valleys in the selected regions, including their geo-referenced locations, was provided by

national research institutions. Four selection criteria for inland valleys were identified on the basis of scientific literature, information from partners, and transect walks: physical accessibility, level of development intervention, crop diversity, and type of water management.

We used a simple multi-criteria ranking procedure 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 were selected, specifically the eight highest-scoring inland valleys in each region. 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. Households were selected using a random number generator. Finally, survey data were collected from 786 farmers: 407 in Côte d'Ivoire and 379 in Ghana.9

Household survey data were collected in July and August 2018. A survey questionnaire was prepared, pre-tested, and administered using Open Data Kit (ODK) data collection software. The data were collected by trained and experienced local enumerators. Each adult respondent has the option to decline participation in the survey.

5.2.4 Description of key variables

5.2.4.1 *Household demographics*

Household composition was reported based on the number of male and female household members per age group. Food security indicators were calculated per household member per day and expressed in male adult equivalents (MAEs) to account for variations in energy requirements by age and sex (van Wijk et al., 2020). This adjustment allowed direct comparisons of energy intake across households of different sizes and compositions. Similarly, income indicators were calculated on a per-person, per-

[9] Number of surveyed farmers per region: Bouake (n=248), Gagnoa (n=159), Ahafo Ano North (n=185) and Ahafo Ano South (n=194).

day basis and expressed in MAE, thereby adjusting for the differing resource needs of household members.

5.2.4.2 *Wild foods*

While many analyses of wild foods include all undomesticated species containing a diverse range of products and species, the RHoMIS questionnaires specifically focused on the most commonly sourced wild foods, which include mushrooms, wild edible fruits, plants, nuts and seeds, bushmeat, fish, insects, and honey. To ensure clarity and avoid conflating semi-cultivated or managed species with truly wild species, the respondents were explicitly instructed to report only products that were not planted or were deliberately managed by the household.

In this study, the terms "wild edible fruits" and "wild edible plants" are used broadly to describe fruits and leafy vegetables, including leaves and flowers. "Bushmeat" refers to edible mammals, birds, reptiles, and amphibians. Households recalled the amounts of wild food items sold and consumed over a 12-month period. To quantify the contribution of wild foods to food security in monetary terms, the dietary energy (kcal MAE^{-1} day^{-1}) obtained from the total wild food harvest (both consumed and sold) was monetised using a replacement cost method, while market prices were used for sales income. Specifically, we computed the cost of purchasing an equivalent amount of dietary energy from the local staple, maize. This resulted in an annual value expressed in United States dollars using purchasing power parity (USD PPP) per MAE day^{-1}), representing the imputed economic value of wild foods for household FA.

Furthermore, the cash obtained from the sales of wild foods was directly included in the calculation of annual household income (USD PPP MAE^{-1} day^{-1}). We calculated the share of total cash income from wild food sales for each household to assess its contribution to cash income, stratified by income quintile. All monetary values were converted to USD PPP, with 2018 as the base year. The detailed methodology for the replacement cost approach is provided in the supplementary information (Box 5.S1).

5.2.4.3 *Household food security*

Household food security was measured using the FA (Giller et al., 2021)indicator. The FA indicator estimates the average amount of potential food energy available in kcal MAE^{-1} day^{-1}. The FA is calculated based on Equation (5.1), where $E_{consumed}$ represents the

energy from direct consumption of on-farm food produce and collected wild foods, E_{income} represents the energy that could potentially be purchased using income from on-farm sales, wild food sales, and off-farm sources such as paid employment, and n_{hh} is the household size in male adult equivalents (Frelat et al., 2016; Hammond et al., 2017; Giller et al., 2021). The amount of energy that could be generated from purchases was expressed in maize energy equivalents.

$$FA = \frac{(E_{Consumed} + E_{income})}{365 \times n_{hhinMAE}} \quad (5.1)$$

Thus, this study defined the following livelihood activities contributing to FA: food crops consumed and sold, wild foods consumed and sold, livestock and livestock products consumed and sold, and off-farm income. To estimate the FA indicator, we used individual farmers' on their annual production and consumption of farm produce, wild food, and livestock produced, and the food purchased with the money they earned (Frelat et al., 2016; Hammond et al., 2017; Ritzema et al., 2017). Household FA was compared to the 2500 kcal MAE^{-1} day^{-1} reference value (Holden et al., 2001). Farm households with less than 2500 kcal MAE^{-1} day^{-1} were considered food insecure (Smith, 2002; UNU and WHO, 2004; Smith and Subandoro, 2007).

Following Wichern et al. (2018), individual households were grouped into three FA classes. Class 1 consists of households with FA values less than 2500 kcal MAE^{-1} day^{-1} (denoting insufficient food availability); Class 2 includes households with FA values ranging from 2500 to 5000 kcal MAE^{-1} day^{-1} (indicating sufficient food availability); and Class 3 comprises households with FA values exceeding 5000 kcal MAE^{-1} day^{-1} (representing excess food availability). For clarity, we refer to Class 1 as 'food-deficient households', Class 2 as 'food-adequate households', and Class 3 as 'food-surplus households'. This classification allows us to compare the relative contributions of wild foods across household food security levels. The monetary value of wild foods across the FA classes was assessed using the replacement cost value.

5.2.4.4*Household Dietary Diversity Score (HDDS)*

The household dietary diversity score (HDDS) is calculated based on the number of food groups that households consume over a given reference period and serves as a proxy indicator of diet diversity (Swindale and Bilinsky, 2006). The HDDS score in the RHoMIS follows the established procedures of Swindale and Bilinsky (2006) in most aspects but

differs regarding the reference period (Hammond et al., 2017). We asked respondents how often foodstuffs from each group were eaten during the 4 weeks, and data were collected during the 'good' and 'bad' seasons to capture the seasonal effects on diversity. The HDDS is constructed based on the ten food groups recommended by the Food and Agriculture Organisation of the United Nations (FAO, 2016). The dietary diversity score results are on a scale of 0 to 10, where 10 represents the most diverse diet in which all ten food groups are eaten at least once.

5.2.4.5*Household income*

The annual household income was expressed in 2018, equivalent to USD, and was converted from local currency using PPP exchange rates (USD PPP MAE^{-1} day^{-1}). The total income was calculated as the annual household income generated from the sale of on-farm products (crops, livestock), wild foods, and off-farm activities (Wichern et al., 2018; Giller et al., 2021). Farm product sales were calculated from local prices retrieved during the survey. Household income indicators were compared to the poverty line set by the World Bank, which is USD 1.90 $person^{-1}$ day^{-1}. According to the World Bank, extreme poverty is measured as people living on less than USD 1.90 day^{-1} (2018 international PPP). The share of total cash income derived from wild food sales was computed for each household and stratified by income quintile.

5.2.4.6 *Household production value*

Household income captures the cash income generated from selling products and off-farm activities. The value of production (USD PPP MAE^{-1} day^{-1}) identifies the potential income that could have been generated if all on-farm products had been sold. The total value of crop production expressed in USD PPP MAE^{-1} day^{-1} was calculated from these data.

5.2.5 Wild food collection and provisioning ecosystem services

To assess the link between the perceived importance of provisioning ecosystem services (P-ES) and wild food collection, we adopted a three-step approach. First, we identified P-ESs as food, fuel wood, fibre and fodder, medicinal, non-timber forest products (NTFPs), and genetic resources based on scientific literature (Costanza et al., 1997; MEA, 2005; de Groot et al., 2012). Second, to assess the perceived importance of these provisioning services, the respondents were asked to rate each P-ES on a five-point

Likert-type scale where (1 = not at all important, 5 = very important). This approach allowed us to quantify the household's perceptions of the contribution of P-ES to well-being.

Table 5.1: Household indicators and units, analysed in this study

Topic	Indicator	Unit
Household demographics	Household size	MAE
	Age	Years
	Education	Years of schooling
	Gender	1= Male, 0=Female
Market variable	Market distance	Minutes
Crops grown	Crop diversity	Number
Household income	Land cultivated	ha
	Livestock holdings	TLU
	Total income	USD ppp $MAE^{-1}day^{-1}$
	Off-farm income	USD ppp $MAE^{-1}day^{-1}$
	On-farm income	USD ppp $MAE^{-1}day^{-1}$
	Wild food income	USD ppp $MAE^{-1}day^{-1}$
Household production	Total value of livestock production	USD ppp $MAE^{-1}day^{-1}$
	Value of livestock prod. sold	USD ppp $MAE^{-1}day^{-1}$
	Value of livestock prod. consumed	USD ppp $MAE^{-1}day^{-1}$
	Total value of farm production	USD ppp $MAE^{-1}day^{-1}$
	Value of crop prod. sold	USD ppp $MAE^{-1}day^{-1}$
	Value of crop prod. consumed	USD ppp $MAE^{-1}day^{-1}$
Wild food collection	Total value of wild food	USD ppp $MAE^{-1}day^{-1}$
	Wild food sold	USD ppp $MAE^{-1}day^{-1}$
	Wild food consumed	USD ppp $MAE^{-1}day^{-1}$
Food security	Food availability	Kcal $MAE^{-1}day^{-1}$
Dietary diversity	Dietary diversity score	No. of food groups
	Dietary diversity scores good season	No. of food groups

*NB: PPP - p*urchasing power parity, *TLU* tropical livestock unit

5.2.6 Econometric model specification for the determinants of wild food collection

We examined the major factors affecting smallholder farmers' wild food collection. Wild food collection was used as a binary dependent variable, based on farmers' responses indicating whether the farm household collected wild food within the previous 12 months (self-reported) before the survey period (1=yes, 0=no). A probit econometric model was used to examine the influence of various socio-economic and institutional factors on farmers' decisions to collect wild foods.

The probit model is specified as

$$Yi = \alpha_i + X_i\beta_i + \varepsilon_i \quad (5.2)$$

where Yi is a dichotomous dependent variable equal to 1 if a farmer collected wild foods and 0 otherwise; Xi is the 1 × K vector of observed explanatory variables

hypothesised to influence the farmer's decision; βi is the K × 1 vector of unknown parameters to be estimated; and Ɛi is the unobserved error term. The variables included in the Xi are socio-economic, institutional, seasonal, and other relevant determinants identified from the literature and economic theory. The names of the variables and their descriptions are provided in Table 5.2. The model was estimated to have robust standard errors that account for heteroscedasticity and provide consistent inference.

5.2.6.1 *Variable names, descriptions and measurements used in the model*

The selection of explanatory variables was guided by existing empirical literature on wild food collection and economic theory. The hypotheses behind the explanatory variables used in the model are indicated in the Supplementary information (Table 5.S1).

Table 5.2: Names and definitions of the variables.

Variable	Description and measurement
Dependent variables	
Wild food collection	Have you been involved in the collection of wild food in the inland valleys in the previous 12 months? (1 = Yes, 0 = No)
Independent variables	
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	Household Size in MAE
IVdist	Walking distance from home to the inland valleys (minutes)
Mktaccess	Do you have access to markets to sell your farm and non-farm products? (1=Yes, 0= No)
Totincome	Total amount of cash generated by farm sales, wild food sales and off-farm (USD PPP, 2018)
Cropdiv	Crops grown (number)
Food insecurity	Food security status of the respondent (1= Food insecure: < 2500 kcal MAE^{-1} day^{-1}, 0 = Food secure: > = 2500 kcal MAE^{-1} day^{-1})
Food insecure month (self-reported)	Number of food insecure months of the respondent (number)
Household dietary diversity	Food groups that respondent households consume over a given reference period (no. of food groups).
Region dummies	
Bouaké	Farmer is from Bouake region (1 = Yes, 0 = No)
Gagnoa	Farmer is from Gagnoa region (1 = Yes, 0 = No)
AnoNorth	Farmer is from the Ahafo Ano North region (1 = Yes, 0 = No)
AnoSouth	Farmer is from the Ahafo Ano South region (1 = Yes, 0 = No)

5.2.7 Data processing and analysis

The data analysis process started with thorough data cleaning, outlier detection, and harmonisation of the variables. The Data were thoroughly checked, and we identified and removed observations with missing or incomplete data or inconsistent values for the key variables of interest that could not be adjusted, such as evident data collection errors. The

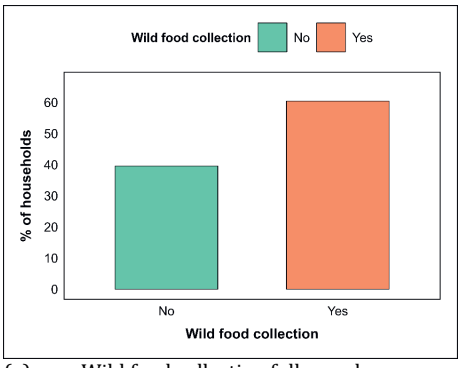
final sample selected for the data analysis consisted of 786 observations. We also examined the distributions of key continuous variables for skewness and applied log transformations where appropriate to meet model assumptions before the regression analysis. All steps and descriptive analyses, including the different graphs and regression analysis, were performed using the statistical software R version 3.6.1 (R Core Team, 2018). At the beginning of the estimation, an ordinary least squares regression and post-estimation variance inflation factor (VIF) were used to check all the variables to determine whether multicollinearity issues were evident in the existing model. Our estimated VIF results range from 1.04-1.37, which suggests that multicollinearity is not an issue (Kleinbaum et al., 2013).

5.3 Results

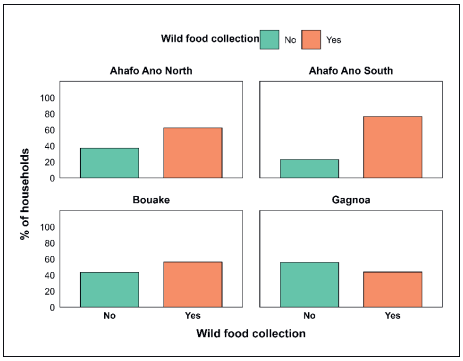
The descriptive statistics of the main variables are shown in Supplementary information Table 5.S2. In all the regions, the median amount of land cultivated was two hectares or more, except for Ahafo Ano North. The household size in the MAE was greater than 4 in all regions, with relatively low variability. Livestock ownership was highest in Ahafo Ano South. The reported median value of crop diversity was 2 and uniform across the study regions, indicative of a farming system where most households grow two or more crops. The income indicators, except for wild food income, were higher in Ahafo Ano South than in the other regions, although the variability among households was high. Wild food income was higher in Gagnoa than in the other regions. Household food availability showed high variability across all regions, which may reflect heterogeneity in production and access. However, the median values were within the expected range in all regions, with particularly high values observed in Gagnoa. The Dietary diversity scores in the good season were higher than those in the bad season in all regions, as expected.

5.3.1 Profile of wild food collectors and role of wild foods

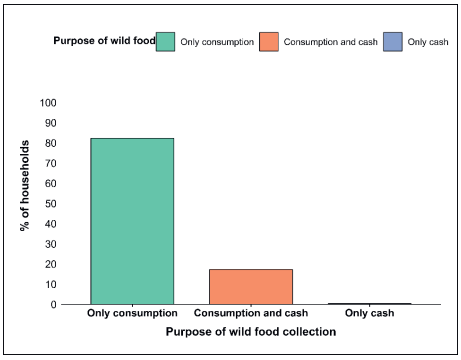
The majority of the sample farmers (60%) reported collecting wild foods (Figure 5.2a). Among these collectors, 85.4% did so for subsistence purposes, whereas 14.6% collected wild foods for cash income (Figure 5.2c). Furthermore, a significant overlap was observed, with almost all cash-generating farmers also collecting wild foods for subsistence. The proportion of wild food-collecting farmers varied considerably by region (Figure 5.2d). Wild food collection was most common in Ahafo Ano South, where 76.3% of the farmers collected wild foods. It was least common in Gagnoa, where 44.0% of the farmers collected wild foods.



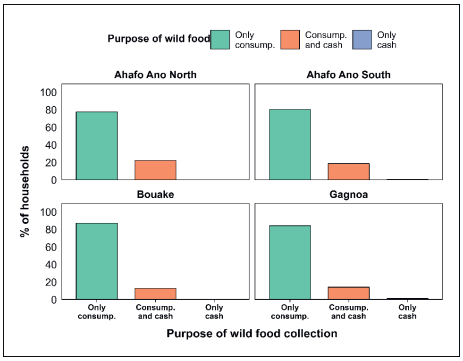
(a) Wild food collection full sample



(b) Wild food collection by region



(c) Purpose of wild food collection full sample



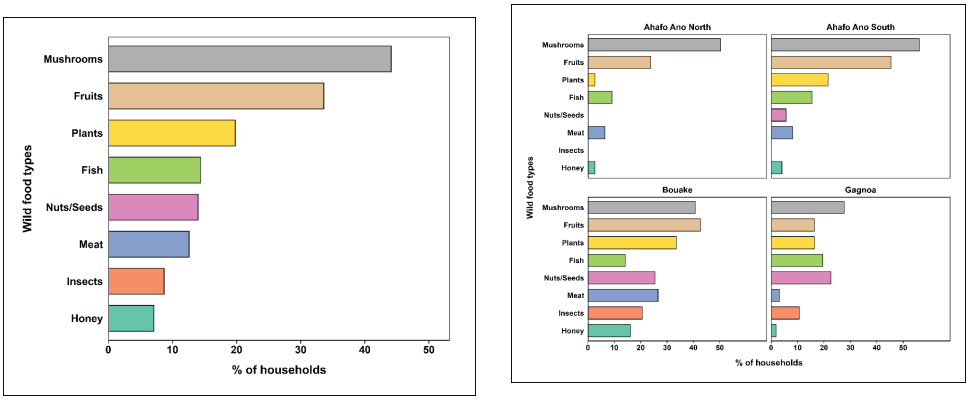
(d) Purpose of wild food collection by region

Figure 5.2: Wild food collection and its purpose

5.3.2 Types of wild foods collected

Farmers collected nearly 87 different types of wild foods. However, the nine most commonly collected wild foods across the full sample were mushrooms, fruits, plants, fish, nuts and seeds, bush meat, insects, and honey, in declining order of importance (Figure

5.3a). Similarly, the proportion of farmers by type of wild food collection across regions was analysed. In all regions, mushrooms and fruits were the first and second most commonly collected wild food types (Figure 5.3b). For other wild foods, there was considerable variation. Fish and plants were the third most commonly collected wild food types in Ahafo Ano North and Ahafo Ano South, respectively. In Bouaké, plants and bushmeat were the third most common collected, whereas in Gagnoa, nuts and seeds, followed by fish were the third most common.



(a) Types of wild food collected full sample (b) Types of wild food collected by region

Figure 5.3: Types of wild foods collected and the proportion of farmers collecting each wild food types

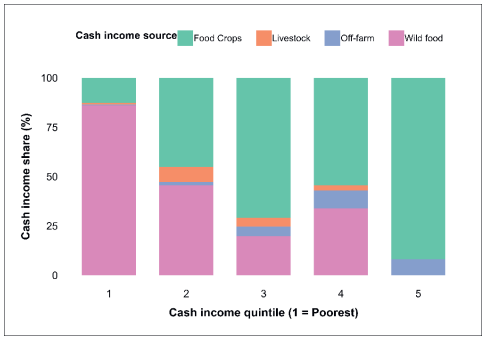
5.3.3 Wild food, income and poverty

The contribution of wild food to cash income varied across farmer income quintiles (Figure 5.4a). The findings indicate that farmers in the poorest income quintile obtained 79.2% of their annual cash income from wild foods, followed by contributions from crops and livestock. In monetary terms, this corresponds to an average annual wild food income of 825.89 USD PPP MEA^{-1}. Income from off-farm labur was minimal, accounting for only 1.7%. In the second income quintile, wild foods also played a significant role, contributing 73.6% of total income, whereas income from crops (24.2%), livestock (1.36%), and off-farm sources (0.8%) remained negligible.

In contrast, in the middle quintile (quintile 3), crops accounted for the majority of income (70.9%), followed by wild foods and livestock. Off-farm income increased to 5.0%. The richest income quintile exhibited the least dependence on wild foods, which contributed to only 0.01% of total annual cash income. Most income came from food crops (91.9%), followed by off-farm activities. In general, wild food contributed a greater

proportion of income to the poorest farmers than the richest farmers. The income share from wild foods declines with a higher income quintile. Conversely, the share of income from crops and off-farm income increases with higher income quintiles. Nevertheless, wild foods continued to contribute, albeit minimally, to income even in the wealthiest quintile. In monetary terms, in the wealthiest income quintile (quintile 5), wild foods contribute to an average income of 118.31 USD PPP MEA^{-1} annually.

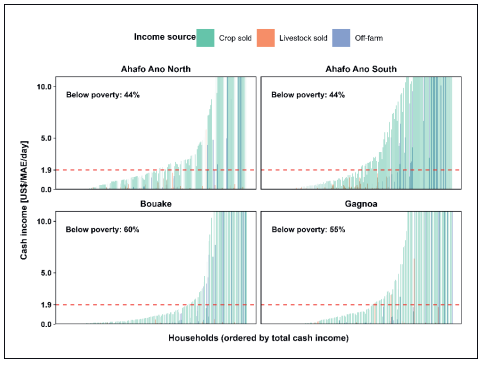
To explore further how the importance of wild food income varies by household wealth status, we disaggregate households into income quintiles from poorest to richest within each region. The share of wild food income showed consistent patterns across quintiles and regions (Figure 5.4b). Wild food sales in Ahafo Ano North and South made negligible contributions across all quintiles. Even among households in the poorest income quintile, the share of wild food income rarely exceeded 2%. Most income was derived from crops and livestock. In Bouaké and Gagnoa, an inverse relationship emerged, in which the poorest quintile farmers derived more of their income from wild foods. Gagnoa exhibited the highest overall dependence on wild foods, particularly among the poorest quintiles.



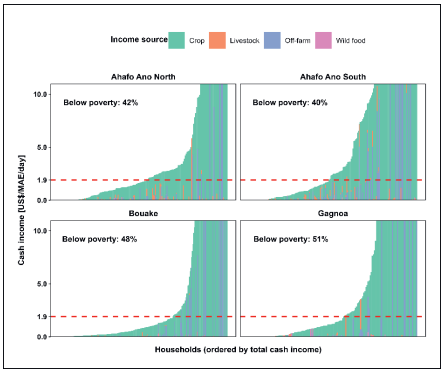
(a) Contribution of wild food to cash income quintile – full sample



(b) Contribution of wild food to cash income quintile - by region



(c) Poverty without wild food



(d) Poverty with wild food

Figure 5.4: Share of wild food income in total annual cash income across farmer income quintiles and percentage of households below the poverty line with and without wild food income. The red dashed line indicates the international poverty threshold of USD 1.90 person^{-1} day^{-1} (World Bank)

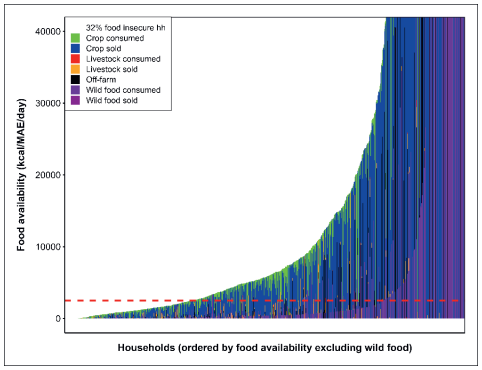
To assess the contribution of wild foods to poverty reduction, we calculated the proportion of farmers below the international poverty threshold of US$1.90 person^{-1} day^{-1}, with and without income from wild food sources (Figures 5.3c and 5.3d). In monetary terms, wild food income covered nearly 47% of the annual poverty line for the poorest quintile. The analysis revealed that including income from wild foods reduced the proportion of farmers below the poverty line. In Ahafo Ano North, the proportion of farmers below the poverty line decreased slightly, from 44% to 42%, when wild food contributions were included. A similar trend was observed in Ahafo Ano South, where the share declined from 44% to 40%. Greater reductions were evident in Bouaké and Gagnoa. In Bouaké, it decreased from 60% to 48%, whereas in Gagnoa, it decreased from 55% to

51%. These results indicate that wild foods make a meaningful contribution to farmer income in the study regions.

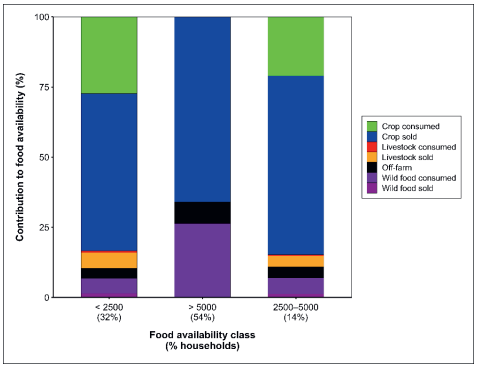
5.3.4 Food security with and without wild foods

The analysis of the contributions of different livelihood activities to FA is presented in Figures 5.5. Wild food contributes 6.7%, 6.6%, and 26.3% to the food availability of the insufficient (< 2500 kcal), adequate (2500–5000 kcal), and excess (> 5000 kcal) food availability classes, respectively. This corresponds to an average wild food energy contribution ranging from 576-2346 kcal MEA^{-1} day^{-1} and a monetary value of 149-470 USD PPP MEA^{-1} annually, depending on food availability classes. Overall, across all food availability classes, crops (sold and consumed) contribute more to food availability, whereas wild foods make a larger relative contribution among surplus households.

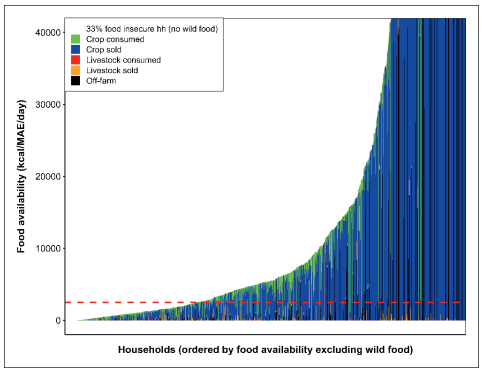
When wild food sold and consumed income were excluded, 33% of the farmers were unable to satisfy their basic caloric needs (Figure 5.5c). In contrast, with wild food sold and consumed income, 31% of the farmers were unable to satisfy their basic caloric needs (Figure 5.5a). The figure also highlights the change in the share of farmers in the food availability classes: when wild food is excluded, the share of farmers in the sufficient food availability class decreases. In contrast, the shares of farmers in the insufficient and surplus food availability classes increase. This shift reflects the uneven role that wild food plays across different farmer types. In particular, food-insecure farmers (Class 1) tend to rely more on wild foods. Excluding the contribution of wild food reduces their overall food availability, causing many to fall below the 2500-kcal threshold or remain in Class 1. Conversely, some farmers in the sufficient food availability class (Class 3) may include wild food in their diets as a supplementary source; excluding it lowers their total food availability, pushing some out of the surplus food availability class into the sufficient class.



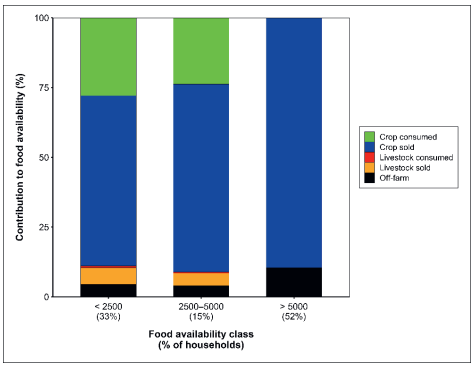
(a) FA in energy per capita per day – full sample with wild food



(b) Relative contribution of household activities to FA per FA class – full sample with wild food



(c) FA in energy per capita per day – full sample without wild food



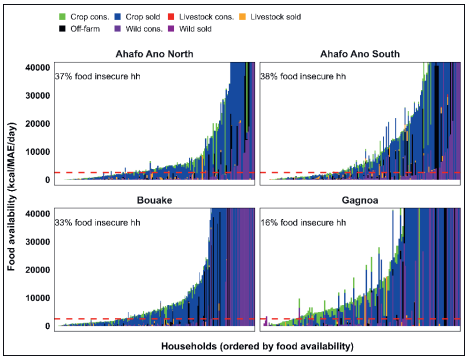
(d) Relative contribution of household activities to FA per FA class – full sample without wild food

Figure 5.5: FA in kcal-1 MAE-1 day-1 and the relative contribution of farmer activities to FA by FA class – full sample with and without wild foods: FA classes: insufficient (<2500 kcal), sufficient (2500–5000 kcal), and excess (>5000 kcal). In (a) and (c), farmers are ordered by increasing FA. Each bar represents one farmer; the bar height indicates FA, and the colours indicate energy sources. The red dashed line marks the threshold of 2500 kcal-1 MAE-1 day-1(male adult energy requirement)

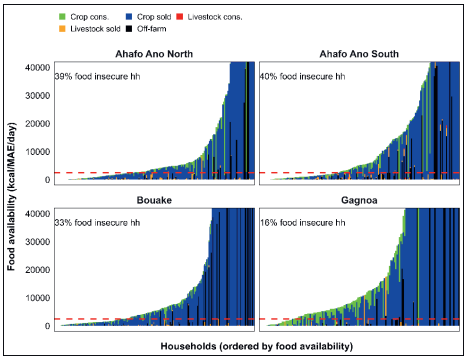
5.3.5 Food security with and without wild foods across regions and FA classes

In all regions, we observed variation among the farmers but a very similar distribution shape, with a few better-off farmers on the right side of the graph and a long tail to the left, representing the poorest farmers (Figures 5.6a and 5.6b). The results revealed that the contribution of wild foods to food security is modest but present (Figure 5.6). The percentage of food-insecure farmers decreased slightly when wild foods were included, particularly in Ahafo Ano North, Ahafo Ano South, and Bouaké, with percentages of 2%, 1%, and 1%, respectively. In comparison, Gagnoa remained unchanged at 16%. A more

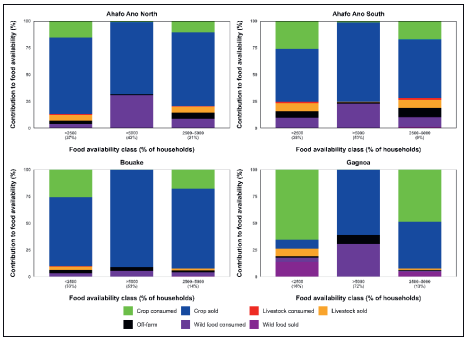
disaggregated analysis by FA class within each region reveals a more nuanced contribution of wild foods. In Ahafo Ano North, including wild foods reduces the proportion of food-insecure farmers in the food deficit and surplus FA classes (i.e., classes 1 and 3). However, it was associated with a slight increase in food insecurity among farmers in the food-adequate class (class 2). This pattern is also observed in the other regions, except for Gagnoa, where no change is recorded in the food-surplus class (Class 3).



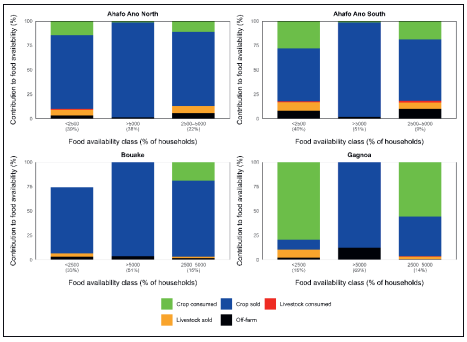
(a) FA in energy per capita per day by region, with wild food



(b) FA in energy per capita per day by region, without wild food



(c) Relative contribution of household activities to FA per FA class by region with wild food



(d) Relative contribution of household activities to FA per FA class by region without wild food

Figure **5.6:** FA in kcal MAE^{-1} day^{-1} and the relative contribution of farmer activities to FA by FA class–by region with and without wild foods: FA classes: insufficient (< 2500 kcal), sufficient (2500–5000 kcal), and excess (> 5000 kcal). In (a) and (c), households are ordered by increasing FA. Each bar represents one household; the bar height indicates FA, and the colours indicate energy sources. The red dashed line marks the threshold of 2500 kcal day^{-1} (male adult energy requirement)

5.3.6 Provisioning ecosystem services (P-ES) and wild food collection

The perceived importance of P-ES differs significantly between farmers who engaged in wild food collection and those who did not (Figure 5.7). Farmers who collected wild foods rated P-ES categories as more important overall. Statistically significant differences ($p < 0.05$) were observed for fibre and fodder, food, genetic resources, medicinal resources, and NTFPs, indicating that wild food collectors attributed greater importance to these P-ESs. No statistically significant differences were found for fuelwood. These findings highlight a clear perceived link between wild food collection and the broader role of ecosystems in supporting household well-being.

Region-wise analysis shows that in Ahafo Ano North and South, perceptions of provisioning ecosystem services, such as fibre, food, fuelwood, genetic resources, medicinal plants, and non-timber forest products, did not significantly differ between farmers who gather wild foods and those who do not. In contrast, in Bouaké and Gagnoa, wild food collectors attributed significantly greater importance to key provisioning services, particularly fibre, genetic resources, NTFPs, and food provisioning (Supplementary information Fig. 5.S1).

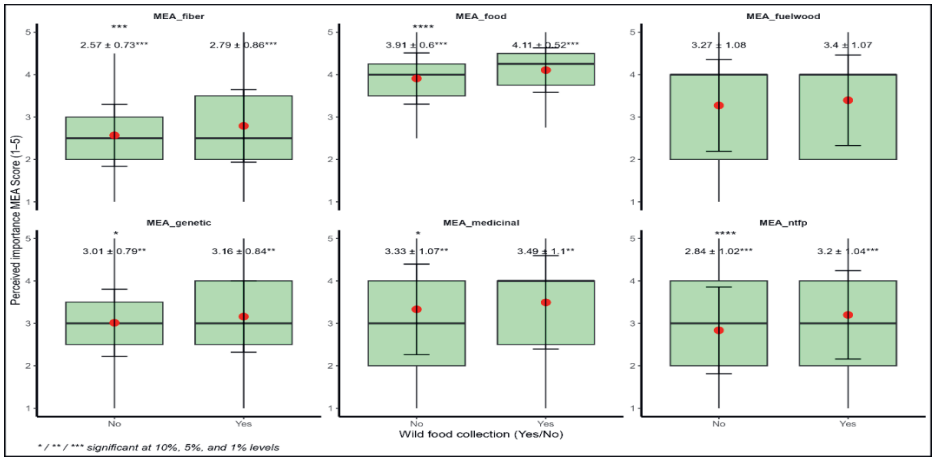


Figure 5.7: Link between wild food collection and perceived importance of P-ES for the full sample. The solid black lines are the median values, and the red dots are the mean values.

5.3.7 Factors affecting household wild food collection

Different farmer, market, seasonal, and food insecurity variables significantly influenced the likelihood of wild food collection (Table 5.3). The age of the farmer was significantly negatively associated with wild food collection. As expected, older farmers were less likely to collect wild foods. Distance from home to the inland valley was

significantly negatively related to wild food collection. As expected, farmers farther from inland valleys were less likely to collect wild foods. Similarly, market access was significantly negatively associated with wild food collection.

Food insecurity and the number of food-insecure months were significantly positively correlated with wild food collection. As expected, food-insecure farmers and farmers with long periods of food insecurity were more likely to collect wild foods. Similarly, household dietary diversity in the good season was positively correlated with wild food collection. Regional differences were also observed where households in the Ahafo Ano South region were significantly more likely to collect wild foods, whereas those in Gagnoa were considerably less likely to do so, relative to the reference region. Other variables, including education, gender, household size, income, and crop diversity, were not significantly associated with wild food collection in this model.

Table 5.3: Probit model estimates of determinants of farmer wild food collection.

Variables	Coefficient	Robust SE
Age	-0.010***	0.004
Educ	0.014	0.011
Gender	0.070	0.152
HHsize	-0.001	0.022
IVdist	-0.294***	0.138
Mktaccess	-0.246***	0.120
lnfarmincome	-0.006	0.027
Food insecurity	0.159***	0.067
Food insecure month	0.034**	0.015
Household dietary diversity (good season)	0.038**	0.021
Bouake	-0.118	0.139
Gagnoa	-0.634***	0.167
Ahafo Ano South	0.344***	0.144
Constant	0.075	0.358
Number of observations	786	

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

5.4 Discussion

Our findings provide empirical evidence on the important role of wild foods in supporting farmers in the inland valley of Côte d'Ivoire and Ghana. The findings also support calls to better integrate wild food considerations into national and regional food security policies (Bharucha and Pretty, 2010; Hickey et al., 2016) and biodiversity management strategies (Sunderland, 2011; Fungo et al., 2023). Such integration could help foster the resilience of food and livelihood systems in these inland valleys.

5.4.1 Extent, patterns, and types of wild food collection

Our findings indicate that 60% of the farmers are engaged in wild food collection, mainly for subsistence. The predominance of subsistence-oriented collection, with only a small proportion collecting wild foods for cash income, reflects the role of wild foods as a critical safety net during periods of food and income shortfall. The findings agree with those of (Brashares et al., 2011; Paumgarten et al., 2018; Mulaudzi and Shackleton, 2025), who highlighted the significance of wild foods in rural livelihood security and resilience to shocks. Furthermore, our findings revealed regional disparities in wild food collection. Such differences may stem from ecological variability and differences in market access, as also observed by (Hickey et al., 2016; Wichern et al., 2018; Nickanor et al., 2023).

Importantly, our findings show that nearly all farmers collected wild foods for sale and for consumption, highlighting the importance of wild foods for both immediate consumption and supplemental income, as also indicated by (Sunderland, 2011; Shumsky et al., 2014). The dual purpose of wild food collection reinforces the notion that wild food resources remain an integral yet often underappreciated component of rural livelihood systems in the inland valleys.

Farmers collected different distinct types of wild foods, with mushrooms and fruits consistently ranking in the top two. The findings underscore the rich biodiversity of inland valley ecosystems and their importance for smallholder diets and agree with the findings of Rodenburg et al. (2014). Furthermore, these findings support earlier work in which wild fruits, leafy vegetables, and mushrooms were reported among the most frequently used wild foods (Fentahun and Hager, 2009; Ojelel and Kakudidi, 2015; Hickey et al., 2016). The predominance of mushrooms is particularly likely to reflect their seasonal abundance and high nutritional value, as also observed by Soro et al. (2019) in Côte d'Ivoire.

Regional differences in the most common wild foods appear to reflect differences in ecosystems and cultural preferences. For example, farmers in various regions of Côte d'Ivoire and Ghana report distinct provisioning ecosystem services such as medicinal plants, fodder, or wild fruits depending on local forest types and water regimes (Alemayehu et al., 2022).

Our findings show that a consistently small proportion of households collect honey align with specialized skills and efforts (e.g., tree climbing and swarm finding required for honey harvesting. This result is also in agreement with Lowore et al. (2018).

5.4.2 Wild foods, income, and poverty

For the lowest income quintile, wild foods contributed more to annual cash income but declined to lower levels among the wealthiest farmers. In monetary terms, this reliance translates into an average wild food income of USD 825.89 PPP MAE^{-1} $year^{-1}$ for the poorest quintile, underscoring the substantial economic importance of wild foods for low-income households. This amount corresponds to nearly 47% of the international poverty line, highlighting that wild foods play a quantitatively meaningful role in poverty reduction.

The inverse relationship between income level and reliance on wild foods is consistent with previous studies, which show that poorer farmers tend to depend more on natural resources for both subsistence and cash (Brashares et al., 2011; Hickey et al., 2016; Nickanor et al., 2023). Regional patterns reveal that in Ahafo Ano North and South, wild foods contributed little to cash income even among poorer farmers, suggesting regional differences in ecosystem resources, market demand, or cultural preferences, as observed by Paumgarten and Shackleton (2009) and Olesen et al. (2024).

The analysis of the proportion of farmers below the international poverty line with and without wild food income further confirms the role of wild foods in poverty alleviation. In Gagnoa and Bouaké, wild food collection was low; however, the proportion of farmers below the poverty line decreased by 12% in Bouaké and 4% in Gagnoa, where wild food income was included. This finding suggests that even limited wild food collection can generate disproportionately high returns, likely due to the economic value of the types of wild foods available, as also reported by Mulenga et al. (2013) and Mollee et al. (2017). For Bouaké in particular, the probable reason could be the ecosystem richness coupled with its relative urban proximity, which likely enhances market opportunities for wild foods.

Research has shown that households closer to urban areas can market wild foods more effectively, resulting in higher income gains (Shackleton and Pandey, 2014; Wichern et al., 2018). The positive wild food income, even among the wealthiest quintile (USD 118.31

PPP MAE-1 annually), further suggests that wild foods retain economic relevance beyond subsistence and function as a complementary income source across wealth groups.

5.4.3 Wild food and food security

The findings show that, overall, including wild foods reduced the proportion of food-insecure farmers. Furthermore, the prevalence of food insecurity has increased by 7–15% in some regions, which confirms that wild foods are used as a safety net and supports the conclusion that wild food plays a complementary but insufficient role in ensuring food security. This result is consistent with the findings of (Bharucha and Pretty, 2010; Hickey et al., 2016). The results also indicated that households in the insufficient FA class (< 2500 kcal day^{-1} $person^{-1}$) depend on wild food to close the caloric gap, and excluding wild foods pushes many below the minimum required caloric threshold, findings similar to those of earlier studies (Brashares et al., 2011; Chakona and Shackleton, 2019; Onomu et al., 2023).

Depending on the food availability class, the contribution of wild foods ranged from 576 -2346 kcal MAE^{-1} day^{-1}, with a corresponding monetary value of USD 149 - 470 PPP MAE^{-1} annually. In simple terms, if wild foods disappeared, households would need to find this amount of money annually for basic energy needs. This is unaffordable for most poor households. However, such dependence also exposes these farmers to risks from environmental degradation, cf. by Koffi et al. (2020).

In the sufficient FA class, the contribution of wild food was modest, and for farmers in this class, wild foods likely supplement diets and offer cultural or nutritional diversity a complementary role previously identified by Onomu et al. (2023) and Shackleton and Pandey (2014). In the surplus FA class, wild foods contribute the largest relative share of calories, which likely reflects that such farmers' wild food use underscores their importance beyond mere subsistence, as part of dietary and cultural identity, a finding that aligns with previous research on the multifaceted value of wild foods (Bharucha and Pretty, 2010; Shumsky et al., 2014; Fungo et al., 2023).

5.4.4 Provisioning ecosystem services (P-ES) and wild food collection

The results indicate that farmers who collect wild foods perceive P-ES as significantly more important than non-collectors. This heightened perception likely stems from the direct, tangible benefits that wild foods provide to household diets and health, a well-established link to dietary diversity in rural communities (Powell et al., 2015).

Furthermore, the perceived significant difference in access to fibre, genetic, medicinal, and non-timber forest products among wild food collectors suggests that wild food collection is embedded within a broader use of ecosystem services, thereby sustaining rural livelihoods beyond direct food consumption and underscoring their multifunctional value for human well-being (Herd-Hoare and Shackleton, 2022).

The perceived importance of genetic resources was significantly higher among wild food collectors. This may reflect the recognition of the role that wild foods play in enhancing agricultural resilience and genetic diversity, which supports crop adaptation to environmental stresses. The dual function of wild foods as sources of immediate subsistence and as reservoirs of adaptive potential for future food production is well-documented (van de Wouw et al., 2010; Jarvis et al., 2011). Similarly, the higher perceived importance of medicinal plants by wild food collectors indicates their vital role in rural health systems, particularly where formal healthcare may be limited, thus reinforcing the indirect benefits of wild foods for food security through health pathways, a critical role emphasised by Lamxay et al. (2011).

A significant difference was observed in the perceived importance of NTFPs among wild food collectors, highlighting the importance of NTFPs as a complementary income or food source. This finding aligns with the work of (Angelsen et al., 2014). In addition, the results indicate that regional differences in how wild food collection influences the perceived importance of ecosystem services highlight its nuanced role within local socio-ecological systems and food security frameworks.

5.4.5 Determinants of wild food collection

In sub-section 5.2.6.1, we hypothesised that education, distance to markets, farm income, and crop diversity are more likely to be negatively correlated with wild food collection. In contrast, household size, household food insecurity, and the number of food-insecure months for the farmers were expected to be positively associated with wild food collection. We did not derive clear hypotheses for the role of age, gender, market access, and dietary diversity in good seasons.

Our findings suggest that older farmers are less likely to collect wild foods. This result may be linked to the physically demanding nature of foraging and wild food collection, given the potential decline in the physical ability of older farmers. Moreover, it is

consistent with the belief that older farmers are potentially more risk-averse, as observed earlier (Mollee et al., 2017; Zhu et al., 2017; Zhu et al., 2024).

Our findings confirm the hypothesis that the distance from home to inland valleys is negatively associated with wild food collection. This is consistent with the findings of some previous studies (e.g., Hickey et al., 2016; Warrier et al., 2024). This may reflect that as the physical distance to wild food collection increases, the opportunity cost of time and effort also increases, particularly for farmers with competing demands such as farming, as emphasised by (e.g., Chopera et al., 2022). Market access has a negative and statistically significant relationship with the collection of wild foods. A possible explanation could be better access to purchased foods and alternative livelihoods. These results agree with the empirical findings of Powell et al. (2015) and Mollee et al. (2017).

As expected, household food insecurity and the number of food-insecure months are positively correlated with wild food collection. This may be because farmers' food insecurity and longer periods of food insecurity increase their reliance on wild food collection as a crucial safety net to cope with food shortages. During these times, limited access to purchased foods and alternative income sources makes wild foods an essential, low-cost resource for sustaining livelihoods, as highlighted in previous studies (Mollee et al., 2017).

Interestingly, dietary diversity during the good season is also positively linked to wild food collection. This may suggest that households incorporate wild foods not only out of necessity but also as part of a diversified diet to increase nutrition, illustrating the dual role of wild foods as both supplements and safety nets (Asprilla-Perea and Díaz-Puente, 2018; Olesen et al., 2024).

5.5 Conclusion and policy implications

This study addresses a critical evidence gap by quantifying the contribution of wild foods to food security and poverty reduction among farmers in the inland valley wetlands of Côte d'Ivoire and Ghana. Our findings demonstrate that wild foods directly increase dietary caloric intake, reduce the proportion of food-insecure households, and provide a vital source of income, increase the number of farmers above the international poverty line. Furthermore, we establish a novel, empirical link between wild food collection and

farmers' awareness of provisioning ecosystem services, highlighting that this practice is embedded within broader ecological knowledge systems.

Our findings are derived from a representative sample of farmers in inland valleys across four regions in Côte d'Ivoire and Ghana. However, inland valley ecosystems in West Africa have unique ecological, cultural, and land-use characteristics that shape wild food availability and collection practices. As such, extrapolating these findings beyond the selected regions, without considering these contextual nuances, may lead to inaccurate interpretations and ineffective interventions. Moreover, the findings are derived from cross-sectional survey data, which restricts causal interpretation, and reliance on 12-month recall data may introduce recall bias. Additionally, some ambiguity may exist in distinguishing truly wild from semi-managed species. Despite these limitations, our findings have several policy implications.

First, 60% of the farmers reported collecting wild foods, mainly for consumption and income. The dual role of wild foods was evident across income groups, particularly among the poorest quintiles. This finding indicates that wild foods potentially play a key role in the livelihoods of inland valley farmers. Therefore, wild foods could be an important component of resilient household food security and sustainable livelihoods. To achieve this goal, wild foods need to be more systematically integrated into national food security and agriculture policies through specific measures such as including them in agricultural extension programs, supporting their sustainable harvest in wetland management plans, and recognising their value in national nutritional guidelines.

Second, our results indicate that wild foods make measurable contributions to household food security and income. Including wild food income reduces the number of farmers below the international poverty line, whereas excluding it from food availability in caloric measures increases the proportion of food-insecure farmers. Therefore, policymakers should integrate wild foods into national food security and poverty assessments by explicitly recognising their role in dietary diversity, caloric intake, and rural resilience while accounting for regional and FA-class variability.

Third, the factors influencing wild food collection, such as age, distance to inland valleys, market access, food insecurity, and seasonal dietary diversity, highlight both structural and situational drivers of reliance on wild foods. Older farmers are less likely to engage in wild food collection, which may suggest that wild food collection is labour-

demanding. Moreover, households experiencing longer periods of food insecurity are more likely to depend on wild food collection, reaffirming the role of wild foods as a safety net during times of scarcity. Thus, policymakers develop targeted support mechanisms that can improve access to wild foods. These may include improving physical access to inland valleys and incorporating wild food knowledge into the existing agricultural extension services. Policies should also recognise and promote the dual nutritional and economic value of wild foods as both a resilience strategy and a contributor to dietary diversity.

Fourth, the findings reveal that farmers involved in wild food collection are more aware of provisioning ecosystem services, which may suggest that wild food use is part of broader ecological knowledge systems. Therefore, policy efforts should recognise and support these local knowledge systems. Policies can build on this knowledge by integrating wild food use and awareness of ecosystem services into natural resource management programs. Strengthening community engagement in managing inland valley ecosystems can reinforce the sustainable use of wild foods, enhance biodiversity conservation, and preserve culturally embedded knowledge that underpins long-term resilience.

Supplementary material Chapter 5

Box 5.S1: Detailed methodology for monetary computation of wild foods to cash income and food security

We employed a three-step procedure for the monetary analysis that converts the percentage contribution of wild foods to cash income and food security into absolute economic values. This also allows direct comparison with the absolute poverty thresholds.

(1) Contribution of wild foods to household income

Step A: Standardisation

We standardised all monetary values of the livelihood sources, including wild foods sold and consumed to 2018 US Dollars adjusted for Purchasing Power Parity (USD PPP) to ensure comparability across the two study countries. We aggregated household income data from four sources: wild food sales, crop sales, livestock product sales, and off-farm income. To account for differences in household composition and consumption needs, we used the Male Adult Equivalent (MAE), which adjusts for age and sex differences among household members.

Step B: Income share computation and quintile analysis

Farmers are divided into five equal groups (quintiles) based on total annual cash income (where Q1=poorest, Q5= richest). For each quintile, we calculated the percentage contribution of wild foods to total cash income.

$$Wild\ food\ share\ (\%) = \left(\frac{\sum Wild\ food\ cash\ income}{\sum(Wild\ food\ sold + Crops\ sold + Livestock\ sold + Off-farm\ income)}\right) X\ 100 \ldots\ldots\ldots \quad (1)$$

Step C: Divide by MAE

Computing the annual cash contribution of wild foods per standardised consumption, we divided the total wild food cash income in each quintile by the total MAE in that quintile:

$$\text{Wild food income per MAE} = \left(\frac{\sum Wild\ food\ cash\ income\ in\ quintile\ i}{\sum MAE\ units\ in\ quintile\ i}\right) \quad (2)$$

Then, to contextualise the wild food income per MAE economic contribution, we compared it to the international absolute poverty line of 1.90 USD PPP day^{-1}, which is computed using:

$$\text{Poverty line (\%)} = \left(\frac{Wild\ food\ income\ per\ MAE\ per\ day}{1.90}\right) \text{X } 100 \quad (3)$$

(2) Contribution of wild foods to household food security

This part of the methods translates the energy contribution of wild foods sold and consumed from kilocalorie measures into monetary values, allowing for direct comparison with market-based food alternatives and quantification of wild foods' role in food security. We used the following steps.

Step A: Calculate the Kcal contribution of wild foods per MAE per day

$$\Delta Energy_{household} = \text{Energy wild food consumption} + \text{Energy wild food sales} \quad (4)$$

Step B: Convert energy to equivalent market value

To monetise the energy contribution, we used the local market price of maize, the most comparable staple food, and also the data availability of the staple, which is maize, as a reference:

$$Monetary\ value_{daily} = \left(\frac{\Delta Energyhousehold}{Energy\ content\ of\ maize\ (kcal/kg)}\right) \text{X Price of maize (USD PPP/Kg)} \ldots\ldots\ldots \quad (5)$$

$$Monetary\ value_{annual} = Monetary\ value_{daily}\ \text{X } 365 \quad (6)$$

Step C: Aggregate by food security classes

The aggregate monetary value the food security classes (i.e. Class 1 consists of households with FA below 2500 kcal MAE−1 day−1 (denoting insufficient food availability); Class 2 includes households with FA ranging from 2500 to 5000 kcal MAE−1 day−1 (indicating sufficient food availability); and Class 3 is made up of households with FA exceeding 5000 kcal MAE−1 day−1 (representing excess food availability). This allowed us to quantify how wild foods contribute differently across households with varying food security status.

$$Monetary\ value_{daily} = \left(\frac{\Delta Energyhousehold}{Energy\ \ content\ of\ maize\ (kcal/kg)}\right) \text{X Price of maize (USD PPP/Kg)} \quad (7)$$

$$Monetary\ value_{annual} = Monetary\ value_{daily}\ \text{X}\ 365 \quad (8)$$

Table 5.S1. Hypothesis of variables used in the probit regression model

No.	Variable name	Hypothesis of the variable
1	Age	Older farm households generally have better traditional knowledge about useful wild foods than younger ones (Tabuti and Van Damme, 2012). However, wild food collection is labour-intensive, and as the household ages, the physical condition of the household tends to decline, and the degree of risk aversion increases compared to younger households (Zhu et al., 2017). Therefore, the respondent's age would have no a priori effect on collecting wild foods.
2	Gender	Studies indicate that in Uganda, for instance, women collect more wild foods than men, as they are traditionally the main collectors (Ojelel and Kakudidi, 2015). However, studies in other African countries (e.g., Ghana, Tanzania, and Rwanda) show that since women devote much of their time to various domestic responsibilities, men are responsible for the collection of wild foods (Cooper et al., 2018). Thus, the effect of gender on the decision to collect wild food is unclear a priori.
3	Education	Households with a higher education level are less likely to collect wild foods, as they tend to seek better-paying job opportunities instead (Mollee et al., 2017). Conversely, a low education level can make it challenging to find employment, leading households to prefer collecting wild foods to meet their food needs (Davenport et al., 2011; Zhu et al., 2017). Therefore, the respondents' educational level would negatively affect the collection of wild foods.
4	Household size	Larger households are believed to have fewer resources and, therefore, are more likely to feel the need to collect wild plants (Mollee et al., 2017). They also have higher labour availability, which can be used to collect wild plants. Therefore, household size would be positively associated with the collection of wild foods.
5	Distance from home to the inland valleys	Households located farther from wild food collection sites are less likely to engage in wild food collection than those located nearby, due to increased time and labour costs associated with distance (Hickey et al., 2016). Therefore, we hypothesise that the distance to home to inland valleys is expected to have a negative association with wild food collection.
6	Market access	Households with access to markets generally have more opportunities to purchase food and sell agricultural products, reducing their dependence on wild foods (Powell et al., 2015). At the same time, market access can also provide incentives to sell wild foods, leading to increased collection, especially where demand exists for niche or seasonal wild products (Pereira et al., 2022). As a result, market access is expected to have no a priori effect on wild food collection.
7	Farm income	In the farming communities, income from farming is a proxy for wealth. It is believed that lower farm income households are more dependent on wild foods for subsistence (Shackleton et al., 2011), while households with higher farm income are believed to have better access to markets to buy commodities such as food and medicine, and they have more choices in types of food (Mollee et al., 2017). Thus, we hypothesise that farm income is negatively related to the likelihood of wild food collection.
8	Crop diversity	It is measured using a simple count of the number of crops grown on the farm during the previous 12 months and is among the most widely used quantifications of diversity at the farm scale as a proxy for production diversity (Hammond et al., 2017). It has often been positively associated

		with household dietary diversity (Sibhatu et al., 2015). Thus, we hypothesise that crop diversity is negatively related to the likelihood of wild food collection.
9	Household food insecurity	It is believed that households experiencing more food insecurity are more likely to engage in wild foods to complement their diet (Kaoma and Shackleton, 2014; Mollee et al., 2017). Thus, we hypothesise that household food insecurity is positively related to the likelihood of wild food collection.
10	Number of food insecure months	It is believed that the number of food-insecure months the household experienced indicates that the prolonged food insecurity increases reliance on wild foods (Fentahun and Hager, 2009). Thus, it is hypothesised that the number of food-insecure months and wild food collection are positively associated.
11	Dietary diversity score in good season	On the one hand, households with high dietary diversity scores in the good agricultural season are more likely to incorporate wild foods to enhance nutritional quality (Asprilla-Perea and Díaz-Puente, 2018). On the other hand, when access to cultivated or purchased food is constrained, dietary diversity becomes low, and households may turn to wild foods out of necessity (Shackleton and Shackleton, 2004; Fentahun and Hager, 2009). Therefore, we hypothesise that the relationship between dietary diversity score and wild food collection is difficult to predict a priori.

Table 5.S2. Descriptive statistics where Median values with IQR in brackets of the main household indicators for the study regions from the RHoMIS database

	Ahafo Ano North	Ahafo Ano South	Bouake	Gagnoa
Household size (MAE)	4.42 (2.4)	4.96 (2.6)	5.38 (3.3)	5.00 (3.4)
Age (years)	42.00 (17)	45.00 (15)	43.00 (19.2)	47.0 (20.5)
Education (years of schooling)	9.00 (9.00)	7.00 (10.00)	0.00 (6.0)	3.00 (6)
Land cultivated (ha)	1.20 (1.6)	2.00 (2.4)	2.00.0 (2)	3.00 (4.12)
Livestock holdings (TLU)	0.00 (0.8)	0.20 (0.9)	0.00 (0.2)	0.00 (0.07)
Crop diversity (number)	2.00 (0)	2.00 (0)	2.00 (0)	2.00 (0)
Total cash income (USD ppp $MAE^{-1}day^{-1}$)	1.76 (3.5)	2.4 (10.4)	0.82 (3.3)	1.21 (8.4)
Total household income (USD ppp $MAE^{-1}day^{-1}$)	2.21 (4.3)	3.03 (13.5)	1.1 (4.7)	1.55 (11.2)
Total farm income (USD ppp $MAE^{-1}day^{-1)}$	2.01 (4.1)	2.48 (12.1)	0.9 (3.5)	1.52 (9.8)
Total wild food income (USD ppp $MAE^{-1}day^{-1}$)	0.04 (0.1)	0.03 (0.1)	0.08 (0.1)	0.2 (0.4)
Total crop production value (USD ppp $MAE^{-1}day^{-1}$)	2.70 (5.9)	3.45 (12.8)	1.27 (3.8)	2.21 (10.8)
Dietary diversity scores good season	7 (3)	6 (3)	6 (3)	6 (3)
Dietary diversity scores bad season	4 (5)	4 (3)	4 (2)	3 (5)
Food Availability (Kcal $MAE^{-1}day^{-1}$)	4006.06 (7480.2)	5716.27 (21908.01)	5683.96 (20852.97)	11069.35 (62643.97)

IQR Inter Quartile Range

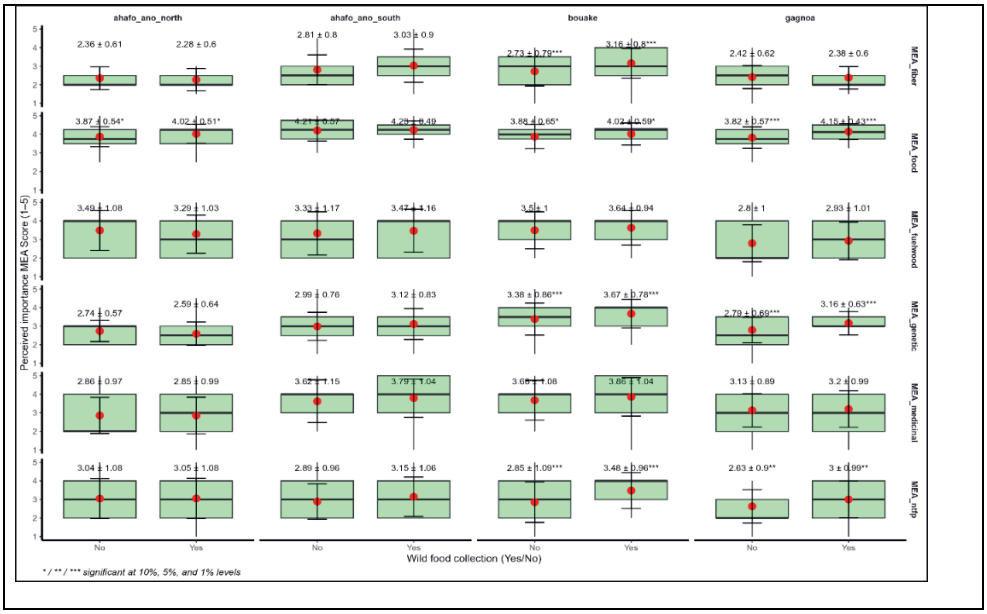


Figure 5.S1: Link between wild food collection and perceived importance of P-ES across regions. The solid black lines are the median values, and the red dots are the mean values

Chapter 6

General Discussion

6.1 Introduction

This thesis was motivated by three key observations. These observations concern both the use and development of rice-based farming systems in the inland valleys and the broader literature on their multifaceted contributions to ecosystem services and biodiversity, contributions that extend beyond rice production. The *first* observation was the lack of an in-depth understanding of how inland valley resources were used at the local level. This lack of understanding hampered the design of suitable management and use strategies for inland valleys, leaving trade-offs between productivity and sustainability largely unexamined. These valleys were often assumed to provide the highest expected benefits for farmers while safeguarding the long-term sustainability of these landscapes. Yet, there has been limited detailed analysis of farms and farming systems at the inland valley level in West African countries (Ibrahim et al., 2021; Dossou-Yovo et al., 2022; Rodenburg and Saito, 2022).

Second, despite significant research efforts to address the challenges of using inland valleys for rice-based farming systems, adoption of the improved technologies and practices remained far below expectations. These efforts have produced improved inland valley use and rice production practices (e.g., Rodenburg and Saito, 2022). However, the adoption rates for these practices remained low in West Africa (Arouna et al., 2017). The low adoption constrained the potential to increase local production, thereby reducing imports and contributing to food security.

Given this low adoption, studies have indicated a need to understand the determinants of adoption decisions (e.g., Komatsu et al., 2022), particularly the socio-economic and resource-related factors (Ibrahim et al., 2021; Rodenburg and Saito, 2022). Moreover, adoption studies often consider low adoption as a failure on the part of farmers, rather than interpreting it as a rational response to opportunity costs, risk, and unequal access. However, little empirical work has examined the factors influencing farmers' decisions to adopt inland valley farming and rice production practices.

Third, current government policies and research efforts have placed more emphasis on rice production and productivity in inland valleys, while largely ignoring the multiple other uses and benefits of these landscapes (Wood et al., 2013; Rodenburg et al., 2014). Indiscriminate use and development of inland valleys for crop production alone have led to the degradation of biodiversity and ecosystem services (Rodenburg et al., 2014). This,

in turn, affects the collection and use of forest products, wild foods, fisheries, and forage resources (Rodenburg et al., 2012).

Despite these negative consequences, ongoing policy and research efforts have not adequately addressed the multiple uses and benefits of inland valleys, which are important to farmers (Wood et al., 2013; Rodenburg et al., 2014). This gap motivated the study to examine farmers' preferences regarding the diverse uses and development options for inland valleys. Understanding farmers' use of the diverse benefits of inland valleys and their preferences is a necessary first step toward sustainable use (Rodenburg et al., 2012; Brosseau et al., 2021).

Thus, taking the inland valleys of Côte d'Ivoire and Ghana as the study countries, the overall aim of this thesis was *to advance our understanding of how the multifunctionality of inland valley wetlands contributes to food security in rice-based farming systems of West Africa*. More specifically, I explored (1) the characteristics of inland valley farming systems and the relevance of ecosystem services for smallholder farmers, (2) the determinants influencing farmers' decisions to adopt inland valley farming and rice production practices, (3) alternative land use and development options in inland valley agriculture that are attractive to farmers, and how do they make monetary trade-offs between specific attributes of these options, and what factors drive potential heterogeneity in farmer preferences, and (4) the contribution of wild foods from the inland valley for farm households' food security and poverty reduction and what factors influence farm households' wild food collection, and the relationship between wild food collection and farmers' awareness of provisioning ecosystem services.

The thesis employed a mixed-methods approach combining farm typology analysis, food security assessment, econometric modelling, choice experiments, and quantitative wild food valuation. Farm typology using PCA and expert input was applied to characterise inland valley farming systems and assess farmers' perceptions of ecosystem services ***(Chapter 2)***. Econometric models were used to analyse the determinants of adoption decisions ***(Chapter 3)*** and factors influencing wild food collection ***(Chapter 5)***. Choice experiments were employed to elicit farmers' preferences for alternative land use attributes ***(Chapter 4)***. Food availability analysis based on kilocalorie calculations and replacement cost valuation was used to assess the contribution of wild foods to household food security and poverty reduction ***(Chapter 5)***.

The remaining sections are organised as follows. The next section presents the summary of the main findings. Section two synthesises the results from the four research questions, emphasising *what farmers value and how that shapes adoption*, *trade-offs between rice intensification and other ecosystem services,* and *heterogeneity among farmers who benefit and who are left behind*. Section three reflects the limitations of the study and directions for future research. Section four discusses policy implications. Finally. The last part concludes by providing a summary of the main findings of the thesis.

6.2 Summary of main findings

Research question 1: What are the characteristics of inland valley farming systems in Côte d'Ivoire and Ghana, and what is the relevance of ecosystem services for smallholder farmers in these regions?

In ***Chapter 2***, we characterised the farming systems in inland valleys and assessed the contribution of ecosystem services to household food security. The study focused on four representative locations: Bouaké and Gagnoa in Côte d'Ivoire, and Ahafo Ano North and Ahafo Ano South in Ghana. We found greater variation in farm characteristics between locations than within locations. Farm households were categorised into four farm types: (1) farmers who rent all the land they cultivate, (2) farmers who own some land and rent additional land, (3) farmers who own and cultivate all their land, and (4) farmers who cultivate only a part of the land they own. Farmers of all farm types in all four locations perceived and attached high relevance to provisioning ecosystem services, followed by regulating ecosystem services. In contrast, farmers attached lower relevance to cultural ecosystem services.

Research question 2: What key determinants influence farmers' decisions to adopt inland valley farming and rice production practices?

In ***Chapter 3***, I explored the determinants of farmers' decisions to adopt inland valley farming and rice production. I found that household characteristics, access to services, and availability of physical capital influenced farmers' adoption decisions. Specifically, older farmers and female farmers were less likely to adopt inland valley farming, though gender did not significantly influence rice production adoption. This reflects unequal access to productive resources and suggests that benefits from inland valley development are unevenly distributed across household groups.

Access to extension services was strongly associated with rice production adoption but not with inland valley farming. Access to credit was strongly associated with inland valley farming but not with rice production. Moreover, distance to market was negatively correlated with both inland valley farming and rice production. Owners of perennial tree crops were less likely to adopt inland valley farming and rice production than non-owners. Livestock ownership was also negatively correlated with the adoption of inland valley farming. Farm size was positively correlated with inland valley farming but negatively correlated with rice production.

Research question 3: What alternative land use and development options in inland valley agriculture are attractive to farmers, and how do they make monetary trade-offs between specific attributes of these options? And what factors drive potential heterogeneity in farmer preferences?

In ***Chapter 4***, I investigated smallholder farmers' preferences for a range of possible alternative land use and development attributes in the context of inland valley wetlands and rice production. I found that farmers have strong positive preferences for alternative land use attributes that increase diversification in terms of the number of on-farm crops and enhance rice production. Importantly, farmers clearly prefer the current level of biodiversity. This preference is expressed in an increased fertiliser subsidy required if biodiversity were to decline. Farmers do have a preference for biodiversity and are willing to invest in it. However, they also appear to recognise that the current level of biodiversity is most beneficial to them. Farmers' livelihoods depend heavily on biodiversity for hunting, fishing, and wild foods, and biodiversity is considered key for food security.

The preference for maintaining the current biodiversity levels further reflects an implicit awareness that rice intensification may come at the expense of ecosystem services that support livelihoods. I also found that farmers' socioeconomic characteristics influence preferences. Specifically, older farmers had a lower probability of choosing the alternative land use attributes. Educated farm households and those with large farm sizes were more likely to choose the proposed land use attributes.

Research question 4: How important are wild foods for farm households' food security (kilocalories) and poverty reduction (income) in the inland valley wetlands of Côte d'Ivoire and Ghana, and what factors influence farm households' wild food collection? And what is the relationship between wild food collection and farmers' awareness of

provisioning ecosystem services?

In ***Chapter 5***, I assessed the contribution of wild foods to household food security and poverty reduction and identified factors influencing wild food collection. Moreover, I assessed the link between farmers' awareness of provisioning ecosystem services and wild food collection. I found that wild food income reduced the proportion of farmers living below the international poverty line by 12%. This may imply that differentiated dependence on ecosystem services, where poorer households rely more heavily on wild foods due to limited access to alternative income sources and markets. For the poorest income quintile, wild food income alone covered 47% of the annual poverty line threshold and contributed to 79.2% of the total annual cash income. Excluding wild food contribution from food availability assessments increased food insecurity by 7–15%. Dependence on wild foods for cash income declined with rising income. But wild food contributes to dietary energy for the wealthiest households.

The result indicated the dual role of wild foods, primarily as a cash income source for the poorest households and as a dietary energy for the better-off households. Wild foods contributed, on average, energy ranging from approximately 576 to 2346 kcal MAE^{-1} day^{-1}. The imputed monetary value of this contribution ranged from 149–470 USD PPP MAE^{-1} annually, depending on the food availability class. Age, market access, and distance to inland valleys were negatively correlated with wild food collection. Food insecurity was positively associated with wild food collection. Farmers with greater awareness of provisioning ecosystem services are more likely to be involved in wild food collection.

6.3 Synthesis of the results

This section synthesises the main results of the thesis across the four research questions, organised into three themes that emerged from the individual chapters.

6.3.1 Farmer values, preferences, and implications for adoption

Perception of ecosystem services: In ***Chapter 2***, we found that farmers of all farm types in all four locations attached the highest importance to provisioning ecosystem services. These services were particularly important for daily energy needs, compensated for poor market access, and provided basic health support where formal health services were lacking or limited.

Furthermore, findings in ***Chapter 2*** indicated that farmers had low awareness of the

cultural ecosystem services of the inland valleys, mainly including recreational, tourism, handicraft, and educational values. This reflects not just a knowledge gap. Rather, it reflects that policy and research have prioritised tangible and quantifiable outputs such as rice yield and cash income over less tangible cultural values. This creates an untapped opportunity for alternative livelihoods (e.g., ecotourism) but also risks imposing external values if not co-designed with communities.

Preferences for diversification and biodiversity: In ***Chapter 4***, I found that farmers have strong positive preferences for alternative land use attributes that increase diversification in terms of the number of on-farm crops and enhance rice production. Farmers clearly prefer the current level of biodiversity, as they appear to recognise that this level is beneficial to them. **In *Chapter 4***, I also found that inland valley farmers' livelihoods heavily depend on biodiversity for hunting, fishing, and wild foods. Biodiversity was considered key to food security, in particular for lower-income households.

In ***Chapter 5***, the importance of biodiversity was further evident. Wild foods provided mainly cash income for the poorest households and mainly dietary energy for the better-off households. Thus, biodiversity degradation would likely harm all households. The preference for maintaining current biodiversity levels may reflect an implicit awareness of trade-offs, in which rice intensification may come at the expense of ecosystem services that support livelihoods, particularly wild foods ***(Chapter 5)***.

Adoption drivers and barriers: Despite these stated values and preferences, **Chapter 3** showed significant drivers and barriers to adoption. I found that household characteristics (age and gender), access to services (extension, credit), distance to market, and physical capital (perennial tree crop ownership and farm size) influenced farmers' decisions to adopt inland valley farming and rice production practices. These adoption determinants may reflect underlying asymmetries in access to land, services, and capital, which shape who is able to benefit from inland valley wetlands. This gap between farmer preferences and what they can adopt represents a central tension for inland valley development.

6.3.2 Trade-off between rice intensification and ecosystem services

Perception of ecosystem services: In ***Chapter 2***, we found that farmers recognised the

importance of provisioning and regulating ecosystem services. Regulating services (water storage and groundwater) were important to the households because water availability is critical for the livelihoods of farmers in the inland valleys. Farmers reported that water is essential for sustaining rice production and rice yields. This suggested that farmers recognise the ecological importance upon which rice production depends.

Biodiversity preferences and trade-offs: Chapter 4 provided empirical evidence that farmers were aware of potential trade-offs between rice intensification in the inland valleys and ecosystem services. I found that farmers showed strong positive preferences for alternative land use attributes that increase diversification in terms of the number of on-farm crops and enhance rice production. Moreover, farmers also clearly preferred the current level of biodiversity. This preference is expressed in farmers' willingness to accept an increased fertiliser subsidy required if biodiversity were to decline. Overall, farmers indicated a preference for biodiversity and ecosystems and showed an implicit awareness that rice intensification may come at the expense of ecosystem services that support livelihoods, particularly wild foods ***(Chapter 5)***.

Wild food contribution to food security and poverty reduction: In ***Chapter 5***, I found that wild foods play a significant role in reducing the proportion of farmers below the food security threshold and the extreme poverty line. Wild food income was associated with a 12% reduction in the proportion of farmers living below the international poverty line. For the poorest income quintile, wild food income alone covered nearly 47% of the annual poverty line, reflecting its important role as a safety net. The exclusion of wild foods from food availability assessments leads to an underestimation of actual food availability and is associated with an increase in food insecurity by 7–15%. In ***Chapter 5***, I also found that the contribution of wild foods to cash income is highly uneven across income groups. Wild foods account for 79.2% of the total annual cash income among the poorest farmers. Their contributions declined with rising income and were marginal among wealthier households.

In ***Chapter 5***, we found that wild food collection was significantly correlated with age, food insecurity, market access, and distance to inland valleys. Another interesting finding was that farmers with greater awareness of provisioning ecosystem services were more likely to be involved in wild food collection. This highlights the role of ecosystem knowledge in sustaining rural livelihoods. It also may influence household food security

and income outcomes through the use and management of wetland ecosystems.

These findings indicated that rice intensification creates practical trade-offs with wild foods and biodiversity. The study confirmed that inland valleys are a multifunctional landscape of competing interests among stakeholders with different levels of power and interests. In this study, those who own land and better-off farmers with greater resource access who can more easily adopt rice intensification are more likely to benefit. Whereas female farmers, landless households, and wild food-dependent farmers are more likely to be disadvantaged and may face reduced access to ecosystem services. This confirmed that in the inland valleys, trade-offs were not neutral. The poorest households are most dependent on wild foods, making them the most vulnerable to trade-offs that prioritise rice intensification over biodiversity.

6.3.3 Heterogeneity among farmers: who benefits and who is left behind

Farm typology and uneven access to resources*:** In ***Chapter 2, we characterised farming systems in inland valleys and found greater variation in farm characteristics between locations than within locations. Furthermore, many farm households were unable to meet minimum daily energy requirements. Access to key resources was not evenly distributed across farm types, as differences in land ownership, gender disparities in resource access, and limited access to credit constrain some households more than others.

Gender and age disparities in adoption: ***Chapter 3*** provided evidence that older farmers and female farmers were less likely to adopt inland valley farming. The finding that female farmers are less likely to adopt reflects the fact that women often have less access than men to critical productive resources and services, including credit, extension services, quality seed, fertilisers, and land rights. This helps explain why female farmers are less likely to adopt, suggesting that the gap is driven not by a lack of interest, but by structural constraints.

Effect of farm size and perennial tree ownership: In ***Chapter 3***, I found a significant influence of ownership of perennial tree crops on agricultural adoption in the inland valley context. Ownership of perennial tree crops was negatively correlated with inland valley farming and rice production. Findings in ***Chapter 3*** further indicated that farm size was positively correlated with inland valley farming but negatively correlated with rice production. These results indicate that adoption is not purely a technical decision but is

shaped by broader livelihood strategies, resource constraints, and opportunity costs, raising questions about which groups are able to benefit from inland valley development. For example, farmers with perennial tree crops or small farm sizes face different opportunity costs and constraints.

Heterogeneity in land use preferences: Chapter 4 also revealed that preferences for alternative land use attributes vary across farmers. Older farmers had a lower probability of choosing diversified or biodiversity-sensitive options, possibly due to shorter planning horizons or high-risk aversion. In contrast, educated farm households and those with larger farm sizes were more likely to prefer the proposed land use attributes. This heterogeneity indicates that willingness to accept trade-offs between rice intensification and ecosystem services is not uniform across the farming population.

Heterogeneity in wild food collection: In ***Chapter 5***, I found that wild food collection was heterogeneous. Older farmers, households with better market access, and those who lived farther from inland valleys had a lower probability of collecting wild foods. However, food-insecure households were more likely to collect wild foods. These determinants suggest access to wild food collection is uneven across households.

Overall, the findings indicated that farmers are not a homogeneous group. Poorer, female, older, landless, and perennial-crop-owning farmers face different constraints and derive different benefits from inland valleys.

6.4 Strengths and limitations of the methodology

In each chapter, I described how the methodologies were chosen and implemented. In this section, I present the strengths and limitations of these methodologies.

6.4.1 Different methodologies and diverse datasets

The thesis's key strength was the use of a comprehensive methodological approach drawing on diverse datasets from multiple sources. ***Chapters 2, 3, and 5*** employed quantitative methods, including farm typology analysis, econometric modelling, and the valuation of wild foods. ***Chapter 4*** applied choice experiments. This combination of methods allowed the study to capture different aspects of the inland valley's multifunctionality. The use of such methods was key to understanding the complex multifunctionality of inland valley wetlands.

To support these methods, in ***Chapters 2, 3, and 5***, primary household survey data

were collected from farmers in inland valleys in two countries, at four locations (Bouaké and Gagnoa in Côte d'Ivoire; Ahafo Ano North and Ahafo Ano South in Ghana) using the RHoMIS tool. The research design, which considered two countries with four locations, strengthens the generalisability of our findings beyond a single context.

Another strength was the methodological approach that focused on farmers' knowledge, preferences, and values. This was evident in the integration of ecosystem services assessment ***(Chapter 2)***, choice experiments ***(Chapter 4)***, and wild food valuation ***(Chapter 5)***. Together, these methods provided a holistic view of the inland valley wetlands' multifunctionality and its implications for food security. Through the application and integration of multiple methods and datasets, the thesis provided a comprehensive picture of how farm typologies, adoption determinants, farmer preferences, and wild food contributions helped to understand the multifunctionality of inland valley rice-based farming systems.

6.4.2 Limitations and future research outlooks

Despite the methodological strengths and the diverse sets of data used, there were limitations related to data availability and quality, which led to issues associated with internal validity, measurement concerns, and external validity. Thus, this section presented these limitations, followed by suggestions for further research.

First, limitations related to internal validity. The results from ***Chapters 2, 3, and 5*** are based on cross-sectional data, which limits the ability to draw causal inferences and raises the possibility of bias from unobserved factors. Due to the observational nature of the data, the findings do not establish causal relationships between the dependent and independent variables; instead, they indicate associations. In addition, data collection over a longer period would have allowed the study to better capture the dynamics of adoption decisions and changes in explanatory variables over time. Future research should employ panel data or experimental/quasi-experimental designs to better identify causal relationships and understand adoption as a dynamic process.

The *second* limitation is related to measurement issues. In ***Chapters 2*** *and* ***5***, a Likert scale approach was used to score the perceived importance of ecosystem services that inland valleys provide to farmers. However, the study has not assessed the impact of agricultural practices on ecosystem services, and the ecosystem services that inland valley crop fields can provide to farmers remain unexamined. Future research should

combine household surveys with ecological assessments and spatial analysis to determine the extent to which inland valley ecosystems are being altered by agricultural intensification.

Third, limitations related to attribute non-attendance. The choice experiment in ***Chapter 4*** included only some of the main attributes of inland valley use and development, although there may be other important attributes that should have been included. Furthermore, differentiating between artificial and intentional attribute non-attendance remains difficult. Future research should explicitly account for attribute non-attendance.

Fourth, a limitation related to the boundary between the identification of wild foods and semi-managed species. In ***Chapter 5***, this limitation arises from the difficulty of clearly distinguishing true wild food species from semi-managed or lightly cultivated species. In smallholder farming systems, particularly in inland valleys, the boundary between wild, semi-wild, and managed species is often fluid. While this reflects the ecological and socio-cultural realities of rural livelihoods, it may lead to a potential overestimation of the contribution of strictly wild foods. The study attempted to address these limitations through clear respondent instructions, standardised definitions, and replacement cost valuation using PPP, which is intended to provide a conservative estimate. Future research could reduce this uncertainty by incorporating species-level ecological assessments, participatory classification of management intensity, or plot-level observations.

The *fifth* limitation is related to external validity. The data collected come from a representative sample of farmers in four locations across two West African countries. While the sample reflects diversity within the study regions, extrapolating these findings directly to other regions without considering contextual differences may lead to inaccurate interpretations. Thus, further work in other inland valley systems could build upon this study to contribute to broader inland valley policy and land use discussions.

6.5 Policy Implications

The findings presented in this thesis have several policy implications at the regional level for promoting the multifunctional and sustainable use of inland valley wetlands in rice-based farming systems. This section summarises these policy implications into three

key priority policy domains: managing trade-offs between rice intensification and ecosystem services, supporting diversified farming systems aligned with farmer preferences, and tailoring adoption policies to heterogeneous household-level constraints.

6.5.1 Managing trade-offs between rice intensification and ecosystem services

The findings indicated that farmers recognised the importance and benefits of ecosystem services in the inland valleys. However, the benefits were unevenly distributed across households. Farmers ranked provisioning ecosystem services highest, followed by supporting and regulating ecosystem services. However, they showed a low level of awareness of cultural ecosystem services. This low awareness points to an untapped policy opportunity. The government has to integrate awareness creation of cultural ecosystem services into existing agricultural extension services. For example, this can be done through training modules and community workshops, and local development plans could strengthen stewardship and diversify livelihood opportunities. However, raising awareness alone is insufficient without creating markets or institutions. Thus, local government can develop an ecotourism certification scheme and payment schemes for cultural landscape preservation and link them to locally existing natural resource management institutions.

We found that farmers' livelihoods depend on biodiversity, and that wild foods from inland valleys play an important role in food security and poverty reduction. Ignoring these resources can lead to an underestimation of household food security assessments. Thus, local land use planners and communities should preserve biodiversity and ecosystems by establishing buffer zones around rice farms and integrating these zones into the village land use plan to sustain household food security in the inland valleys.

I found that rice production practices in the inland valleys often overlook differences in local conditions, existing land uses, or ecological sensitivity. This would likely lead to differentiated outcomes, where better-resourced farmers may benefit more, while poorer households risk losing access to critical ecosystem services. Therefore, policies and strategies aimed at increasing national rice production should find an optimal balance between food production, particularly rice, and the conservation of other ecosystem services by minimising trade-offs.

Policy makers in consultation with the communities should operationalise such a

balance through spatially differentiated strategies, including zoning approaches using existing land use and ecological data or future spatial assessments. For example, a zone could include targeted intensification in suitable areas, a restoration zone, and biodiversity and wild food protection zones. Depending on the zones, the government should establish incentive-based mechanisms such as targeted subsidies or payments for ecosystem services as a potential instrument consistent with observed trade-offs, that protect biodiversity-rich zones while allowing productivity gains.

In addition, the zoning approach must be accompanied by safeguards that explicitly protect the access rights of vulnerable groups, including wild food collectors and landless farmers. Such trade-offs are not neutral but involve choices about whose interests are prioritised and who bears the costs. Therefore, the government could, for example, establish a cross-ministerial task force of agriculture, environment, and social protection as an illustrative coordination mechanism reflecting the cross-sectoral nature of inland valley trade-offs to map inland valleys by existing use, not just agricultural potential.

6.5.2 Supporting diversifying farming systems aligned with farmers' preferences

I found that farmers prefer diversified production systems embedded in biodiversity-rich areas, and wild foods are a key component of diversified livelihoods. These preferences vary across households, reflecting differences in livelihood strategies and resource endowments. Understanding the diversity of rice-based farming systems and farmers' preferences is important for national agricultural research systems and national government planners in developing context-specific strategies that can improve food security while preserving ecosystem services.

This has significant policy implications: the diverse livelihood options offered by inland valleys, such as alternative income-generating activities, should be explored alongside crop production, rather than focusing solely on rice expansion. Such alternatives can also reduce pressure on ecosystem services. Furthermore, policymakers should consider and prioritise crop diversification as a key livelihood strategy, particularly where climate change threatens many farmers' food security and livelihoods. Agricultural extension services should support diversified farming systems, not just rice monoculture. The government should provide training for extension officers on crop diversification and biodiversity benefits and include biodiversity and wild food indicators in their annual performance metrics. This policy must safeguard that protect the access rights of wild

food collectors and landless farmers to ensure that they are not excluded from the diversification benefits.

At the same time, farmers' preference for maintaining current biodiversity levels indicates that diversification strategies should emphasise functional and productivity-enhancing diversity rather than externally imposed conservation targets that may conflict with farmers' perceived welfare outcomes. This would also contribute to the regulation and support of ecosystem services, many of which depend on the type of crop diversification strategy implemented. Policymakers, together with community leaders, could support participatory land use planning where communities map their preferred diversification strategies (e.g., maintaining wild food collection zones alongside rice fields) and then align extension and credit programs accordingly. This empowers smallholder farmers to make decisions according to their preferences while ensuring that collective choices do not undermine long-term ecosystem functions.

6.5.3 Addressing heterogeneous household constraints in adoption policies

I found that the decision to adopt inland valley farming and rice production practices is influenced by types of physical capital (farm size, perennial tree crop ownership), institutional factors (access to extension, credit, distance to market), and household factors (age, gender). In addition, farmers' willingness to accept trade-offs depends on perceived welfare impacts**,** and wild food collection is also influenced by various socio-economic, institutional, and seasonal variables. This highlights that different groups of farmers face distinct constraints and opportunities.

Given this heterogeneity, policies aimed at increasing rice production must be flexible and tailored to local contexts to enhance food security effectively. Therefore, policymakers should first focus on the common variables that affect adoption, including increasing the frequency of extension agent visits and expanding rural microfinance institutions. At the same time, policies should explicitly consider differences between resource-poor and better-off households, as these differences shape both the capacity to adopt innovations and the benefits derived from them. Besides, policymakers must also account for specific contextual factors, including the technological needs of different farmers and physical capital variables, particularly ownership of perennial crops, which creates opportunity costs for rice adoption.

Moreover, the government should look to strengthen local institutions and service

providers, mainly extension services, by improving information delivery and expanding rural micro finance institutions to minimise liquidity constraints. This should also include addressing power relations that influence who can access resources, services, and decision-making processes, as unequal access may limit the effectiveness of well-designed interventions. Strengthening extension services should also involve recognising and integrating farmers' local ecological knowledge, particularly related to wild foods and ecosystem services, into advisory systems, thereby increasing relevance, trust, and long-term sustainability.

6.5.4 An integrated approach for multifunctional inland valleys

In sum, ensuring the sustainable and multifunctional use of inland valley rice-based farming systems requires an integrated policy approach that explicitly links four domains: (i) agricultural policy (supporting diversified farming systems, beyond rice monoculture); (ii) environmental policy (safeguarding biodiversity, wild foods, and ecosystem services); (iii) social protection and land tenure policy (ensuring equitable access to resources and addressing power asymmetries); and (iv) financial and extension policy (providing credit, training, and performance metrics that reward biodiversity and wild food outcomes).

6.6 Conclusion

During my research stay in Côte d'Ivoire and Ghana, West African governments continued to pursue rice self-sufficiency policies in the inland valleys. The policies prioritised increasing rice production and productivity through area expansion and intensification in the inland valleys. In line with these policies, research efforts placed greater emphasis on increasing rice production and productivity in the inland valleys. Yet, limited attention was given to the multiple and diverse uses and benefits of inland valleys on which many farmers' livelihoods depend. However, this thesis has shown that these wetlands are far more than rice production and productivity. Inland valleys are multifunctional landscapes that provide wild foods, biodiversity, and ecosystem services important for food security, including for the most vulnerable households.

Empirically, the thesis advances our understanding of the diverse uses and development of inland valley wetlands in four ways. *First,* smallholder farmers recognised and valued a wide range of ecosystem services and were willing to accept trade-offs to maintain biodiversity. This indicates that multifunctionality is not only an ecological concept but also a reality that shapes livelihood decisions. *Second*, structural inequalities

in access to credit, extension services, and physical capital (e.g., farm size and ownership of perennial tree crops) constrained the adoption of inland valley practices.

Third, the analysis found that farmers strongly prefer biodiversity and diversified farming systems. These preferences were not abstract but associated with observed welfare outcomes (e.g., food security, income). This finding suggested that conservation policies aligned with local preferences may be both ecologically and socially effective. *Fourth,* it provided quantified evidence that wild foods contribute to poverty reduction and improved food security. The analysis also quantified dietary energy and cash income from wild foods. The findings showed that wild foods serve a dual role: as an income safety net for the poorest and as a dietary supplement for the better off households. However, even when wild foods are available, access to them is highly unequal. Factors such as land ownership, gender, distance to markets, and age determine who benefits. This suggest that policies promoting rice intensification without addressing access asymmetries risk increasing existing inequalities.

Methodologically, the thesis provided an approach combining farm typologies, adoption models, choice experiments, and wild food accounting to assess trade-offs in data-poor contexts. This approach could be adapted to other wetlands where multiple competing land uses exist.

Overall, the thesis advanced the scientific understanding of how the multifunctionality of inland valleys contributed to food security, while offering testable hypotheses for future research in similar socio-ecological contexts. Practically, the findings call for an integrated policy approach that explicitly manages trade-offs between rice intensification and biodiversity conservation, supports diversified farming systems aligned with farmer preferences, and protects access to wild foods for the poorest households.

Ultimately, this thesis demonstrated that food security in inland valley wetlands cannot be achieved through rice production alone. The multifunctionality of inland valleys, which balances rice production with ecosystem services, can be achievable, but more likely when existing trade-offs are explicitly addressed, access rights are secured, and policies are tailored to the heterogeneous realities of smallholder households. Recognising and protecting wild foods, maintaining biodiversity, and ensuring equitable access to ecosystem services are not obstacles to development. The future of inland valleys lies not in choosing between rice and nature, but in managing both for the benefit of all who depend on them.

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Summary

Inland valley wetlands in West Africa are believed to be a conducive environment for rice-based farming systems and have gained increasing attention as a solution to improve food and nutrition security for smallholder farmers. Rice is the most consumed cereal in West Africa. However, domestic production meets only 40-50% of demand, leaving the region heavily reliant on imports. Moreover, the 2008 global surge in cereal prices triggered food shortages and social instability across West African countries. As a result, extensive rice production in the inland valleys has been considered a quick fix to address food security challenges. However, extensive rice production has often degraded ecosystem services in inland valleys without adequately meeting food production demands. This narrow focus on rice production has limited attention to the broader functions and services provided by inland valley systems, creating a knowledge gap that this thesis addresses.

Research on the diverse uses and benefits of inland valleys and farmers' preferences for alternative uses and development attributes in the inland valleys is limited. Therefore, this thesis aims to explore options to realise the potential of inland valleys to contribute to national food security. Four specific research questions guide the thesis: (1) the characteristics of inland valley farming systems and the relevance of ecosystem services for smallholder farmers, (2) the determinants influencing farmers' decisions to adopt inland valley farming and rice production practices, (3) alternative land use and development options in inland valley agriculture that are attractive to farmers, and how do they make monetary trade-offs between specific attributes of these options, and what factors drive potential heterogeneity in farmer preferences, and (4) the contribution of wild foods from the inland valley for farm households' food security and poverty reduction and what factors influence farm households' wild food collection, and the relationship between wild food collection and farmers' awareness of provisioning ecosystem services.

This thesis undertakes an in-depth characterisation of the current inland valley farm and farming systems. In addition, it investigates the factors that influence farmers' decisions to adopt inland valley farming and rice production, and it explores farmers' preferences for alternative land use and development attributes. Lastly, it examines and quantifies the contribution of wild foods to household food security and poverty reduction. In ***Chapter 1***, I introduce key concepts and the theoretical background of the

research, the research questions, and the methodology of the studies. ***Chapters 2-5*** present the main empirical studies of the thesis.

Chapter 2 provides a detailed characterisation of the current inland valley farms and farming systems, and farmers' perceptions of ecosystem services. The study identified four farm types: (1) farmers who rent all the land they cultivate, (2) farmers who own some land and rent extra land, (3) farmers who own and cultivate all their land, and (4) farmers cultivating only a part of the land they own. I show that variations in farm households' demographic and economic characteristics, and institutional services, such as access to credit and agricultural extension services, are greater between locations than within locations.

The majority of farmers attach high relevance to inland valleys' provisioning of ecosystem services, particularly the ability to provide food, followed by regulating services such as water storage. However, attached lower relevance to cultural ecosystem services, indicating an untapped policy opportunity for ecotourism or cultural preservation. The findings contribute additional insights to the literature on the use and development of inland valleys by highlighting the diversity in farmer resource endowments and underscoring the importance of the multifunctionality of inland valleys.

In ***Chapter 3***, the thesis identifies the factors influencing farmers' adoption decisions regarding inland valley farming and rice production. Results show that access to credit and extension services, and physical capital, significantly influence adoption. In particular, owners of perennial tree crops are less likely to adopt inland valley farming and rice production than non-owners. This provides new insight into the role of ownership of perennial tree crops in agricultural adoption. Moreover, farm size has a different effect on adoption depending on the type of agricultural practices. Particularly, female farmers and older farmers were less likely to adopt inland valley farming, reflecting unequal access to productive resources rather than a lack of interest. This highlights that adoption constraints are heterogeneous across household groups. The findings underscore that strengthening local institutions and service providers to target specific groups of farmers can help promote the adoption of inland valley farming and rice production.

Chapter 4 builds on the results of ***Chapter 2*** and goes a step further to explore

farmers' preferences for alternative land use and development attributes. I find that farmers demonstrate a strong preference for diversified production systems that balance rice production with biodiversity conservation and other ecosystem services. Moreover, on average, inland valley farmers express a preference for maintaining current biodiversity levels, as they perceive that further biodiversity loss would negatively affect their livelihoods and increase the need for subsidies. Importantly, this preference for the status quo does not reflect opposition to biodiversity conservation; rather, it indicates substantial heterogeneity in biodiversity preferences and suggests that farmers view existing biodiversity levels as broadly optimal for their production systems.

Farmers appear willing to invest in biodiversity, but their support is shaped by their own assessments of how much biodiversity is beneficial, which in this context corresponds to current conditions. Taken together, the results in ***Chapters 2 and 4*** suggest the importance of integrating farmers' priorities and the diverse use of inland valleys to achieve sustainable and socially acceptable inland valley management strategies.

Chapter 5 deals with assessing the extent of wild food collection from inland valley wetlands and quantifying its monetary value in supporting household food security and income. Building on the findings of ***Chapters 1*** *and* ***4*****,** this thesis demonstrates that wild foods directly enhance dietary caloric intake, reduce the proportion of food-insecure households, and provide a vital source of income, lifting farmers above the international poverty line. For the poorest income quintile, wild food income alone covered 47% of the annual poverty line threshold and contributed 79% of total annual cash income. Excluding wild foods from food availability assessments would increase measured food insecurity by 7–15%.

Building on the findings of ***Chapter 1***, this thesis further establishes a novel, empirical link between wild food collection and farmers' awareness of provisioning ecosystem services. The results show that farmers involved in wild food collection demonstrate greater awareness of provisioning ecosystem services. The imputed monetary value of wild food energy contribution ranged from 149 to 470 USD PPP per adult equivalent annually, depending on food availability class, and the dietary energy contribution ranged from 576 to 2346 kcal MAE^{-1} day^{-1}. These findings highlight that

wild food collection is embedded within broader ecological knowledge systems. The study also finds that structural and situational drivers influence wild food collection.

Taken together, the results from ***Chapters 4 and 5*** suggest that farmers' management of inland valleys is shaped by both ecological considerations and livelihood needs, emphasising the importance of integrating farmers' priorities, diverse resource use, and socio-economic heterogeneity to achieve sustainable and socially acceptable inland valley management strategies. Thus, I argue that wild foods could be integrated into national food policies in a more tailored way to support both ecosystem management and rural livelihoods.

Three main themes emerge from the thesis findings. *First,* farmers' values and preferences play an important role in shaping adoption and land-use decisions. Farmers strongly prioritise provisioning ecosystem services, attach lower relevance to cultural ecosystem services, and express a clear preference for maintaining current biodiversity. *Second*, the results highlight important trade-offs between rice intensification and ecosystem services. Wild foods function as a critical safety net for the poorest households, contributing both income and dietary energy. When intensification is not carefully managed, it can undermine the ecosystem services that rural livelihoods depend upon, creating long-term social and environmental costs. *Third*, the findings underline the importance of recognising heterogeneity among farmers. Different groups experience distinct constraints and benefits. Female and older farmers, landless households, and farmers who own perennial tree crops are consistently less likely to adopt inland valley practices. Poorer households, meanwhile, depend more heavily on wild foods for both subsistence and income generation. Together, these patterns suggest that one-size-fits-all policies may unintentionally deepen existing inequalities rather than reduce them.

Chapter 6 provides a synthesis of the main chapters and discusses the broader policy implications, limitations of the research findings, and ways forward for future research. Overall, this thesis shows that efforts to increase national rice production could benefit from considering the diverse uses and benefits of inland valleys and farmers' preferences. The findings carry three priority policy implications: (i) managing trade-offs between rice intensification and ecosystem services through spatially differentiated zoning and buffer zones; (ii) supporting diversified farming systems aligned with farmer

preferences for biodiversity; and (iii) tailoring adoption policies to heterogeneous household constraints, including gender, age, land access, and perennial crop ownership.

Furthermore, this thesis indicates the need to support farmers' diverse livelihood strategies, strengthen institutional capacities such as extension and credit services, and raise awareness about the broad benefits provided by inland valleys. Methodologically, this thesis combined farm typology analysis, econometric modelling, discrete choice experiments, and replacement cost valuation of wild foods.

The findings contribute to the debate on whether extensive rice production poses a threat or an opportunity for inland valley ecosystem services. Evidence presented in this thesis shows that inland valleys directly support household food security and income, implying that poorly balanced extensive rice production degrades ecosystem services with significant consequences. In conclusion, this thesis demonstrates substantial room to realise the contribution of inland valleys to sustainable food security in West Africa.

Appendices

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Tesfahun Alemayehu Belew

Appendix 1: Rural Household Multiple Indicator surveys combined with additional inland valley questions

Hello. My name is _____, and my colleague's name is _____. We are coming from Africa Rice Center, Wageningen University, and the regional research institute of Côte d'Ivoire and Ghana. We are here to ask you questions about your livelihood activities, inland valley farming systems, inland valley production potential and constraints, and farmers' attitudes and views on ecosystem services in the inland valleys. The information will provide useful insights on how to improve the sustainable use of inland valleys, considering the views of the communities in the inland valleys. We decided to operate the survey in 16 inland valleys in Côte d'Ivoire (i.e., Bouake and Gagnoa) and 16 inland valleys in Ghana (i.e., Ahafo Ano North and Ahafo Ano South). Your community is one of those involved and will directly benefit from this information as we look at how to improve inland valleys in the country. In each of the inland valleys, a few farmers have been randomly selected to participate in the household survey, and you are one of these. The household survey is for research purposes, and your responses will be aggregated with those from other farmers in the country to get a general overview of the inland valley farming systems. The information you provide is confidential. This means that we will not publish the information with your name. If you have any questions, don't hesitate to ask. Please note that participation is voluntary.

'Can we now continue with the survey?'

Thanks a lot for your participation. We appreciate your help!

A. Household identification

General information		
A1. Date (dd/mm/yyyy)		
A2. Country		
A3. Local currency		
A4. Region name		
A5. Inland valleys names		
A6. Name Interviewer		
A7. Household GPS code	Latitude decimal degrees	Longitude degrees
A8. Consent to provide information for this survey	[1=Yes, 0=No]	
A9. Household ID		
A10. Name of the respondent		
A11. Position in household [Code A]	[code A]: 1= Household head, 2= Joint household head. 3= Spouse of head 4= Other family member 5= Other, non-family member	
A12. Household type [code B]	[code B]: 1= Live together; 2= Single, divorced or widowed;3= Spouse works away;4= Other adult in charge;5= Child headed	

B. Household information

B1. How many people live in your household_____ (**Include only members who live there at least 3 months per year)?**

B2. Person no.	B3. How old are they?	B4. Is the respondent male or female? [1= male 2= female]	B5. Is the respondent the head of the household? [1=Yes 2=No]	B6. What is the head person's marital status? [Code A]	B7. What is the highest level of education the head person has completed? *	B8. How are you related to the head?
P1 (hh-head)						
Please ask each person in the household: Are they the head of the household? Are they male or female? How many years of schooling have they received? How old are they?						
P2						
P3						
....						

[Code A] 1= has a partner (married or non-married) 2= single 3= divorced 4= widowed 5= other (specify)….

**: Number of years of formal schooling (put N/A (not applicable) if age is less than 6 years)*

B9. What is the household head's primary source of income? [Code A] (select all that apply)	B10. What is the household head's secondary source of income? [Code A] (select all that apply)	B11.Does the head person often live and work away from home? [1= Man work-away, 2=Both works away 3= None work away]	B12. How many years of farming experience does the household head have? (Years since started farming)
[Code A] 1= crop farming 2= livestock (including poultry) 3= trading* livestock (products) 4= trading* crop products 5= hired farm worker 6= formal employment (non-farming) 7= petty trader. 8= tourism 9= fishing 10= other (specify .....)			

** Trading refers to intermediary activities, buying from other farmers and selling again*

C. Farmland Sizes

Land ownership, land use, land tenure and other characteristics of land

C1. Does your household own land, rent land, or use common land? [1= Yes 2=No], If yes for C1 ask the next questions

C2. Land size	C3. How much land does your household own?	C4. About how much land does your household rent in for use?	C5. Tenure status of the land [code A]	C6. About how much land does your household rent out for other people to use?	C7. In total, how much land did you use for growing crops during the last 12 months?	C8. Who in the family owns your household 's land? [Code B]	C9. Who works on your land household members or other people too? Consider crops, livestock, any farm activities. [Code B]	C10.What type of farm labor arrangements have you been used in farming? [Code C]
area								
unit: [1= Acre, 2= Hectare]								
[Code A]1=title deed (e.g., purchase, inheritance) ;2=owned but not titled; 3=public land 4=rented-in/share-cropped;5=rented out; 6=communal;7=other (specify)			[Code B] 1= Male head/senior; 2= Female head/senior; 3= Male adult. 4= Female adult; 5= Male youth (15-30yrs);6= Female youth (15-30yrs); 7= Male child (<15 yrs);8= Female child (<15 yrs)					[Code C] 1= Household labor 2=Hired labor 3=Reciprocal labor

Plot details

C11.How many separate plots of land do you own or use? *(Answers the following information for each specific plot)*

C12.Plot No.	C13.What is the size of this plot?	C14.What is the tenure system of this plot? [Code A]	C15.How many minutes' walk is it from your home to the plot?	C16.Is your plot accessible? [Code B]	C17.How steep is the slope of the plot as perceived by you? [Code C]	C18.Do you ever practice fallow in this plot? [Code D]	C19.If yes, for C18, how long have you left this plot fallow?	C20.What is your total plot size (fallowed)
1.								
2.								
3...								
....								
[Code A]1=title deed (e.g. purchase, inheritance) ;2=owned but not titled; 3=public land 4=rented-in/share-cropped;5=rented out; 6=communal;7=other (specify)					[Code B] 1=easy (by bike or motorbike); 2=medium (by foot); 3=difficult (not by foot)		[Code C] 1=Very steep; 2=Steep 3=Gentle 4=Flat	[Code D] 1= yes; 2=No

D. Housing

Husing condition of the household

D1. What is your home ownership? [code A]	D2. How many rooms are in your home?	D3. What are the floors in your home made of? [code B]	D4. What are the walls in your home made of? [code C]	D5. What is the roof of your home made of? [code D]	D6. What is your main water supply for domestic use? [code E]	D7. Do you have electricity supplied to your home? [code F]
[Code A] 1=owned 2=rented 3=borrowed 4=other (specify)		[Code B] 1=earth 2=cement 3=tiles 4=other (specify)	[Code C] 1=earth/mud 2=wood/bamboo/iron 3=cement/bricks 4=other specify	[Code D] 1=grass 2=iron/ asbestos 3=tiles 4=other (specify)	[Code E] 1=wells, 2=stream, 3=pond, 4=borehole, 5=other (specify)	[Code F] 1=yes 2=no

Hint: If the compound has more than 1 housing area for HUMANS, then take ownership and materials related to the MAIN HOUSE but including the number of rooms from ALL HOUSING FOR HUMANS. For Electricity, respond YES if the house has supply to the house (either to mains, generator, solar etc.) – note this doesn't include the use of battery or oil lamps.

E. Inland valley questions

General IV information

E1. Do you currently use resources (land, water, fauna, flora, NTFP) * form inland valleys? [1=Yes, 2=No]

If yes for the above E1, complete the table below.

E2. For about how many years have you been using inland valley resources? [Code A]	E3. For what economic purposes do you use the inland valley? [Code B] – select all that apply)	E4. What services other than economic ones do you get from the inland valleys? [Code C] – select all that apply)	E5. How close is your house located to the IVs? [Code D]	E6. Do you experience any problems from living in or close to the IVs? [Code E]	E7. If yes for E6, what problems do you experience? [Code F] – select all that apply)	E8. What advantages do you experience from living in or close to an IV? [Code G] – select all that apply)	E9. Which activities have expanded in and around the IVs during the past 5 years? [Code H] – select all that apply)
[Code A] 1=less than 5 years 2=1-5 years 3=6-10 years 4=11-15 years 5=more than 16 years	[Code B] 1=cultivation of crops, vegetables, and fruits 2=grazing 3=fishing 4=collecting wood (energy, construction) 5=hunting 6=tourism 7=handicrafts 8=Others (specify)	[Code C] 1=recreation (e.g., swimming, relaxing) 2=rituals (e.g., sacrificing and feasting) 3=sanitation (e.g., washing clothes and bathing) 4=household and animal drinking water 5=Other (specify)	[Code D] 1=inside the IVs 2=very close (less than 30 min walk) 3=close (30-60 min walk) 4=more than 60 min walk	[Code E] 1=yes 2=no	[Code F] 1=malaria infection 2.water borne disease 3=increased salinity 4=rising water level 5=unintended flooding of surrounded farmland area 6=water shortage 7=animal diseases 8=other (specify)	[Code G] 1=access to farmland 2=access to irrigable land 3=Access to fishing 4=easy access to household and animal drinking water 5=access to grazing land 6=other (specify)	[Code H] 1=irrigation 2=settlement 3=urban 4=food crop area (e.g., rice) 5=cash crop area (e.g., vegetables, fruits) 6=tourism 7=other (specify)

** Resources refers to Natural resources in the inland valley that include Water, land both agricultural and grazing land, forests, wood, etc*

E10.Have you been involved in farming in the inland valleys in the last 12 months? [1=Yes, 2=No]

E11.Have you been involved in rice farming in the last 12 months? [1=Yes, 2=No]

If the answer to E11 is yes, then complete the following table on rice farming.

E12.For how long have you been farming rice?	E13.Who in your household is involved in rice	E14.How many times do you grow rice per year on	E15.Which type of rice production system do you practice?	E16.Which rice variety do you grow? [Code D] (Select all that apply)	E17.If irrigated, which source of water do you use? [Code E]	E18.Do you rotate rice with any other crops? [1=yes, 2=No]	E19.Rice production objective [Code F] (Select all that apply)	E20.Proportion of paddy rice sold on the market. [1=100-75% 2=75-50%	E21.For which reasons are you farming in the

(Number of years)	farming [Code A] (Select all that apply)	the same field? [Code B]	[Code C] (select all that apply)		(Select all that apply)			3=50-25% 4=25-0%]	IV? [Code G] (select all that apply)
[Code A] 1=Adult males, 2=adult females, 3=Children [<15 years	[Code B] 1= 1 time 2=2 times 3=3 times	[Code C] 1= rain-fed lowland 2=irrigated lowland, 3=rain-fed upland 4-rain-fed upland and rain-fed lowland,5-Other (specify)		[Code D] 1=Bouake 189;2=Wita 9 or Nimba 3=IR841;4=Orelus6;5=GT11 6=Nerica1;7=Nerica4;8=Nerica14 9=Nerica L14;10=Nerica L19 11=Other (specify)		[Code E] 1=surface water, 2=groundwater 3- Other (specify0	[Code G] 1=self-consumption 2=market purpose 3=Other (specify)	[Code J] 1=lack of land at upland; 2=loss of soil fertility at upland; 3=Uncertainty of rainfall at upland 4=drought at upland; 5=crop failure at upland;6= availability water at IV;7=fertile soil at IV 8=other (specify)	

E22.The next questions are about the amount of land in the valley which is used for agriculture.

	E23.How much of the inland valley area is currently occupied by agriculture?	E24.How much of the inland valley area was occupied by agriculture 5 years ago?	E25.How much of the inland valley area was occupied by agriculture 10 years ago?	E26.How much of the inland valley area was occupied by agriculture 20 years ago?
Land use change				
	[Code A] 1=0 -25%, 2=25-50%, 3=50-75%, 4=75-100%			

F. Inland Valleys Resource Management

F1. Do you think that human activities (e.g., farming) within and around the inland valley have caused any undesirable effects/e.g., Deforestation, water and land use conflict, water pollution, grazing conflict, and health issues in the inland valley so far? [1=Yes 2=No]

If yes for **F1,** complete the following table:

F2. Are you worried about the inland valley becoming overused? [Code A]	F3. To what extent do you agree that households have, in general, benefited from IV resources? [Code B]
[code A]1=none; 2=little ;3=medium; 4=high	[Code B]1=Strongly disagree; 2=Disagree;3=Neither agree nor disagree;4=Agree;5=Strongly agree

G. Inland valleys use problems.

G1. Types of problems	G2. Have you experienced or faced weed problems in your farm in the inland valleys? [0=yes; 1=No;]	If yes for G2, how severe are these constraints? [1=High 2=Medium 3=Low]
Have you experienced any conflicts between other people using resources?		
Have you experienced any problems with water management?		
Have you experienced problems with flooding		
Have you experienced any challenges with the governance and management of inland valleys?		
Use of technology (e.g., for farm operations)		
Have you faced any constraints with the use of inputs (fertilizer, pesticides)?		
Access to good quality of seed		
Have you faced any constraints with labour availability?		
Have you faced any problems with weeds?		
Have you faced any problems with pests?		
Have you faced any problems with a lack of knowledge about suitable crops?		
Have you faced any problems with a lack of knowledge about crop rotations?		
Others (Specify)		

H. Crop information (crops grown, fertility)

H1. Does your household grow any crops? [1=yes 2=No]

H2. Which crops were grown by your household during the last 12 months?

H3. Out of all the crops grown by your household in the inland valleys in the last 12 months, which were the primary and second most important?

H4. Do you have access to markets to sell your farm products? [1=Yes, 2= No]

H5. What is the nearest waking distance from home to the place of the nearest market in minutes?

H6. Did you receive information about prices for the sale of crops before you began planting? [1=Yes, 2=No]

H7. Did you receive information about prices for the sale of crops before you went to sell them? [1=Yes, 2=No]

Detailed information for each crop

	Values for last 12 months												Who:	
ID	H8. Crop	H9. Area	H10.Area unit	H11.Production (LWU)	H12.LWU	H13.Fertiliser	H14.Manure	H15.Consumption (LWU)	H16.Vol sold. (LWU)	H17.Total value last year	H18.Where sold	H19.How much was traded or given? (%)	H20.Did the work	H21.Sells the crop
1														

Area unit: 1= Acre, 2= Hectare	LWU: 1= Kg, 2= Tonne, 3= Bunch	Where sold: 1= Market 2= Neighbour 3= Government	Work and control: 1= Man2= Woman3= Child

I. Land management and agricultural inputs

I1. Did you use any crop inputs during the last 12 months? What did you use? [1=Yes, 2=No]
I2. On which crops did you use fertilizers during the last 12 months?
I3. Which crops did you use manure or compost on during the last 12 months?
I4. On which crops did you use pesticides during the last 12 months?
I5. For which crops did you use improved seed varieties during the last 12 months?
I16.Mineral fertilizer used in the last 12 months.

	I17.How much fertiliser in total was used during the last 12 months? Types of input	I18.Unit (bags, kg)	I19.Volume
1			
	Types: 1= Urea, 2= DAP, 3= CAN, 4= SSP, 5= TSP	**Unit:** 1=Kg, 2=Bag, 3= Debe, 4= Tenga, 5= Kasuku can, 6= Ton	

J. Irrigation uses in the inland valleys

J1. Did you grow any crops in the inland valleys under irrigation during the last 12 months? [Code A]	J2. Which crops did you irrigate during the last 12 months?	J3. What type of irrigation method did you use [code B]	J4. Which months did you irrigate?
[code A]1=Yes; 2=No	[code B] 1=Basin dug around plant; 2=Gravity-fed (river diversion); 3=Sprinkler;4=Drip irrigation; 5=Electric or diesel pump; 6= others (specify).		

K. Wild foods

K1. Did your family gather any food/feed from outside of your farm? [1=Yes, 2=No]

ID	K2. Type of wild food	K3. What months do you collect this	K4. What percentage of total food/feed is in these months
1			
2			
Food/feed types: 1= Animals; 2= Fish; 3= Vegetables; 4= Fruit 5= Nuts;6= Honey;7= Mushrooms;8= Grass (feed) 9= Weeds (feed)			Importance of food/feed: 1= All or nearly all (87-100%) 2= More than half of it (63-87%) 3= About half of it (38-62%) 4= Less than half of it (13-37%) 5= A small amount (1-12%)

L. Institutional support and governance of inland valleys

L1. Are there agencies or institutions in your area that manage and govern the inland valley's resources? [1=yes 2=No]. If yes for K1, complete the table below.

L2. What type of institutions manage the inland valleys and their ecosystem services? [Code A]– select all that apply)	L3. If public institutions are selected, which types? [Code B]– select all that apply)	L4. If private institutions are selected, which type? [Code C]– select all that apply)	L5. Which governance, regulatory, and planning instruments work in your area? [Code D]– select all that apply)
[Code A] 1=ANADER 2-CNRA 3-AfricaRice, 4-Development Project(specify) 5=Private institutions 6=National/international NGO's environment institutions 7= none 8-Others (specify)	[Code B] 1=Environmental protection agency 2=Public certification bodies 3=National/local registries 4=Others (please specify)	[Code C] 1=Civil society organizations 2=Private business 3=Others (please specify)	[Code D] 1=Land use planning (regional &sub-regional land-use planning, protected area management planning, water resource planning) 2=Policy and regulation (National legislation, national strategies, and action plans) 3=Market based governance (labelling, certifications, eco-labels for agriculture 4=Others (specify)

M. Access to credit

M1. Do you have access to credit services? [1= yes, 2 = No] If yes for I1, would you please give us the following details

M2. Accessible credit or Lending sources [Code A]- select all options that apply.	M3. What was the intended use for the loan? [Code B]- select all that apply)	M4. Do you experience problems with access to credit? [code C]	M5. If yes, what are the major credit service problems [Code D]- select all that apply)
[Code A]	[Code B]	[Code C]	[Code D]

1=NGO 2=Informal lender 3=Formal lender (bank / financial institution) 4= Friends /Relatives 5= Savings/credit groups	1= Farm inputs/equipment, 2= Livestock purchase & management (incl. chicken), 3= Non farming business, 4= School fees, 5= Household items, 6= Purchase land / 7= build house, 8=Other (specify)	1= yes, 2= No	1=Loan is not available in time 2: Terms for repayment are not favourable 3=Payback period is short 4=others (specify)

N. Extension services

N1. Have you received any visits by extension officers in the last 12 months? [1=No; 0=Yes]. If yes for N1,

N2. Service areas	N3. Used in the past 12months. [0=No, 1=Yes]	N4. If yes for N3, no. of visits in the last 12 months?	N5. Level of satisfaction with the service [code A]
Rice production			
Improved agronomic practices			
water management/Irrigation			
Inland valley resource use and management strategies			
Resource use conflict management			
[Code A]: 1= Very dissatisfied, 2= Dissatisfied, 3= Neutral /not sure, 4= Satisfied, 5= Very satisfied			

O. Key livestock species

O1. Does your household own any livestock or animals? [1=Yes 2=No]

O2. Which livestock does your household keep?

O3. Cattle	O4. Number	O5. Number. bought the last year	O6.1) Local, 2) foreign or 3) both	O7. Number sold in the last year	O8. Total amount earned from selling	O9. How did you sell? ^	O10.Who looks after? *
Cows							
Calves/young							
Bulls							
Oxen							
sheep							
Goats							
Pigs							
Chicken							
Others (specify)							

^**How sold**: 1= Market, 2= Farmer (non-neighbors), 3= Neighbors, 4= Trader

***who looks after**: 1= Men, 2= Women, 3= Children

Animal products - cattle

O11.**Cattle**	O12.How much milk (l/day)	O13.How many cows are milked	O14.Dry season yield	O15.Total amount earned from selling	O16.Product made	O17.How much is produced per year	O18.Where did you sell?	O19.Percentage sold	O20.Percentage consumed/ given	O21.Who did most of the work?	O22.Who decides when to eat?
Cows											

Product list:	Where sold:	Percentage:	Who did most of the work
1= Mtindi, 2= butter, 3= cream, 4= cheese, Other	1= Collection center, 2= cooling center, 3= Hawker, 4= Neighbor	1= All or nearly all (87-100%) 2= More than half of it (63-87%) 3= About half of it (38-62%) 4= Less than half of it (13-37%) 5= A small amount (1-12%)	1=Men, 2=Women, 3=Children

Non-ruminant manure

O23.Non-ruminants	O24.Approximately what proportion of their time do they spend inside?	O25.How much of the manure do you put on crops?	O26.How much of the manure do you store?	O27.How much of the manure do you use as fuel?
Pigs				
Chicken				
Ducks				
Rabbits				

Percentage: 1= All or nearly all (87-100%); 2= More than half of it (63-87%); 3= About half of it (38-62%); 4= Less than half of it (13-37%); 5= A small amount (1-12%)

P. Debts and aid

P1. Have you received aid from the government, NGOs, or other organizations in the last 12 months? [1=Yes, 2= No]

P2. What types of aid have the household received from the government or organizations during the last 12 months?

P3. About how much of the food eaten by your household was from aid sources?

	P4. Type	P5. How much (units)	P6. Volume	P7. What did you do with it?	P8. Who decided to do this?
1					
2					
3					

Type:	Units:	What seeds did you get?	What did you do with it?		Who decided to do this?
1= Food 2= Money 3= Fertilisers 4= Seeds 5= Animals (write type) 6= Other	1= Dollars 2= Kg 3= Each 4= Bags	1= Staple crop 2= Cash crop 3= Traditional varieties 4= Improved varieties	1= Buy food 2= Buy agricultural inputs 3= Buy durable possessions 4= Payed school fees 5= Pay other bills and debts 6= For savings 7= Eat it 8= Sell it	9= Trade 10= Give away 11= Used on staple crop 12= Used on cash crop 13= Planted 14= Still have it 15= They died 16= Stolen	1= Man 2= Woman 3= Child 4= NA

Q. Off-farm income

Q1. Did your household get involved in off-farm income-generating activities in the last 12 months? [1=Yes 2=No]
Q2. In total, how important is the off-farm income, i.e., how much of the total income is it (code below)?
Q3. Consider all the money earned in the last 12 months from selling farm produce and from the cash activities we just discussed. Did more money come from sales of farm produce or more from the off-farm cash activities?
Q4. When spending the money that is earned from off-farm sources, what sorts of things does your household spend it on?
Q5. When spending the money that is earned from sales of farm produce, what sorts of things does your household spend it on?

Off-farm income		Q8. Who did most of the work?	Q9. Who controls the revenue?
Q6. What are those sources of off-farm income?	Q7. Income (% of total livelihood; see classes)		
Work on other farms			
Work on other enterprises			
Other (specify...)			
Importance of Income: 1= All or nearly all (87-100%); 2= More than half of it (63-87%) 3= About half of it (38-62%); 4= Less than half of it (13-37%) 5= A small amount (1-12%)			**Work and control:** 1= Man; 2= Woman; 3= Child

R. Progress out of Poverty indicator [Ghana]

R1. PPI	R2. Response: Yes / No
Are all household members ages 5 to 17 currently in school?	Yes / No
Can the female head or the head's wife read and write? Which languages?	Yes / No
What is the main construction material used for the outer wall?	Earth / Cement, tiles, timber / Other: _____
What is the main building material of the roof of the main dwelling?	Mud/grass, leaves, thatch, bamboo/metal, other
What type of toilet facility is usually used by the household?	No toilet facility (bush, beach), or other/ Public toilet (e.g., W.C., KVIP, pit pan)/ Pit latrine, bucket/pan
What is the main fuel used by the household for cooking?	None, no cooking/ Wood, crop residue, sawdust, animal waste, or other/ Charcoal or kerosene/ Gas or electricity
Does any household member own a working box iron or electric iron?	Yes / No
Does any household member own a working television, video player, VCD/DVD/MP3/MP4 player/iPod, or satellite dish?	Only television/ Video player, VCD/DVD/MP3/MP4 player/iPod, or satellite dish (regardless of T.V.)/
Does any household member own a working bicycle, motorcycle, or car?	None/one/two/three or more
How many bicycles, mopeds, motorcycles, tractors, and motor vehicles do you own?	None / one / two or more
Does your household have any radios or radio cassettes?	Yes / No
Do you have an iron (charcoal or electric)?	Yes / No
How many tables does your household own?	None / One / Two / Three or more

S. Food security

Food Security	

Is there a time of year when there is less food available compared to other times?	
If so, usually for how many months is the period of less food available?	
Which months?	
During the worst month	
How often do you ever worry that there will not be enough food for your household?	
How often was someone in the house not able to eat the kinds of food they wanted to?	
How often did someone have to eat a less varied variety of foods?	
How often did somebody have to eat some foods that they really did not want to eat?	
How often did somebody have to eat smaller meals than they wanted?	
How often did somebody have to eat fewer meals than they wanted?	
How often was there no food to eat of any kind in your household?	
How often did somebody have to go to sleep hungry at night?	
How often did somebody have to go a whole day and night without eating anything?	

Options:1= everyday (or almost every day);2= a few times a week (more than two times per week); 3= once a week; 4= once a month; 5= rarely; 6= never

T. Nutritional diversity

Options:1= everyday (or almost every day); 2= a few times a week (more than two times per week); 3=

During the worst month, how often do you eat: grains or flour?	
During the worst month, how often do you eat: starchy roots or platanos?	
During the worst month, how often do you eat: vegetables?	
During the worst month, how often do you eat: fruits?	
During the worst month, how often do you eat: beans, legumes, nuts or seeds?	
During the worst month, how often do you eat: meat or organs from animals?	
During the worst month, how often do you eat: Fish?	
During the worst month, how often do you eat: Eggs?	
During the worst month, how often do you eat: Milk or things made out of milk?	
During the worst month, how often do you eat: Fats, like oil, butter, margerine, lard?	
During the worst month, how often do you eat: Sweet things made from sugar?	
During the worst month, how often do you eat: Other foods, like drinks or foods in packets?	
And now the same questions, but during the good season.	
When there is more food, in a typical month, how often do you eat:	
Grains or flour?	
Starchy roots or platanos?	
Vegetables?	
Fruits?	
Beans, legumes, nuts or seeds?	
The meat or organs from animals?	
Fish?	
Eggs?	

once a week; 4= once a month; 5= Rarely and 6= never

Appendix 2: Choice experiment survey questionnaire

Hello. My name is ..... and I am coming from Africa Rice Centre/Wageningen University and research. We are conducting this survey to assess farmers' preferences and views about the different alternatives for sustainable inland valley use and development. Understanding farmers' preferences and perceptions will provide useful insights to improve policymaking towards the sustainable use of IVs, considering the interests of the communities in the IVs. The information you provide is confidential. This means we will not publish the information with your name or give it to someone else. If you have any questions, do not hesitate to ask. Please note that participation is voluntary.

'Can we now continue with the survey?'
Thanks a lot for your participation. We appreciate your help!

A)General information

A1.	Date of Interview **[**DD/MM/YYYY**]**:		/ / 2021	
A2.	Enumerator Name:			
A3.	Did the household consent to the interview? **[**0= NO; 1=YES**]**			
A4.	Country **[**0=Côted'Ivoire; 1=Ghana**]**			
A5.	Regions names [1=Gangoa; 2=Bouake; 3= Ahafo Ano North; 4= Ahafo Ano South]			
A6.	Inland valley name			
	1= Bamoro	9=Dignago	17=Abum Tepa	25=Ahrewam
	2=Djebenoua	10=Gagnoa Ville	18=Anynasuso	26=Asukese
	3=Kondoukro	11= Gnadi	19=Dwaaho	27=Asuokor
	4=Kpangbabo	12=Grozoudelle	20=Krouboa	28=Biem
	5=Langbassou	13=Kogne	21=Meredane	29=Mankran
	6=Lokakpli	14=Ouragahio	22=Ntenwe	30=Nyaase
	7=Mbe2	15=Takoa 1	23=Subriso	31=Nyamebekyere
	8=Ngatta Sakassou	16=Zapata Gessiho	24=Yaw takribrikrom	32=Yawboadi
A7.	Common currency unit [0= CFC Franc; 1= Ghanaian Cedi- GHS**]**			
A8.	Time interview started:			
A9.	Time interview ended:			
A10.	Household GPS Coordinates:	Altitude (meter above sea level)	Latitude (N/S):	Longitude (E/W):

B) Choice experiment

To the interviewer

Read the scenario described below to the respondent farm households and describe the printed and laminated illustrative visual images of the choice sets (Figure 1). Please ensure that the respondent farm households give attention to (and understand) the description before proceeding to the following questions.

We are presenting to you three possible inland valley use and development alternatives. You should always choose only the most preferred and attractive out of these alternatives. Please also note that although this is only a survey, the options presented here are realistic and could apply to your inland Valley production situation in the future. Therefore, we kindly ask you to carefully understand and consider the available alternatives and choose if this is a real inland valley use and development option. Your preference is essential to better understand smallholder farmers' preferences to make the use and development of inland valleys sustainable. Any future options will be designed based on the smallholder farmers' preferences in the inland valleys. Moreover, the result obtained from this study can help to make some general recommendations about how to improve and sustainably use and develop the inland valleys in an environmentally friendly manner.

Suppose in the choice set, you have three inland valley use and development alternatives you can choose from (Table 2 in the main text).

If you choose alternative 1, you will get an average rice yield of less than or equal to 1 ton/ha per cropping season. This means your rice yield declined by at least half of what you are currently producing.

However, you have the potential to grow three crops, including rice, per cropping season, which helps to reduce your risk of depending only on one crop. Moreover, the number of native trees, wild animals, and other plant and animal species will improve and increase by half from the current level. However, you are required to implement more biodiversity conservation measures (e.g., use of your piece of land for a community-managed plant garden or forest reserve, preserving trees and useful species during land preparation). As a result, you may get more non-crop benefits from the inland valleys and sustainable crop production in the future. If you agree to choose this alternative, you will receive a subsidy of 200kg NPK + 100kg Urea fertilizer from your government annually applied to one hectare. This is an equivalent of approximately (1205GHS) or (94,500CFA) or (210$).

If you choose alternative 2, you will get an average rice yield greater than or equal to 3 tons/ha of rice per cropping season. This means that because of the technical support from AfricaRice and extension services from the national systems, your rice yield increased by at least half of what you are currently producing. Moreover, growing two crops, including rice per cropping season, remains the same. However, the number of native trees, wild animals, and other plant and animal species will worsen and decline by half. This is because you will focus on rice production and the unsustainable exploitation of inland valley resources. As a result, your non-crop benefit declined, and the rice yield declined over time. If you agree to choose this alternative, you will not get any fertilizer subsidy (0GHS) or (0CFA) or (0$).

The third alternative is the status quo or the current scenario alternative. If you select the status-quo alternative, you will get an average rice yield of 2 tons/ha per cropping season. Moreover, growing two crops, including rice per cropping season, remains the same. However, the number of native trees, wild animals, and other different plant and animal species is low, with a minimal number of plants, trees, and animal species compared to the past. This is because you are not working on biodiversity conservation measures. Instead, you are using the resources unsustainably compared to the past. If you agree to choose this alternative, you will not get any fertilizer subsidy (0GHS) or (0CFA) or (0$). What we would like to know from you is which of these three alternatives would you prefer most.

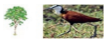
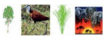
Attributes	Alternative 1	Alternative 2	Status-quo
Rice productivity	At most 1 ton/ha ≤ 	At least 3 ton/ha ≥ 	2 ton/ha 
Crop diversity	5 crops 	2 crops 	2 crops 
Biodiversity	50% improving & EFAP 	50% decline & GAP 	Low & GAP 
Subsidy	255$ year-1 ≈ 1205GHS = 200kg NPK + 100kg Urea 	no subsidy 	no subsidy 
Which alternative would you choose most	☐	☐	☐
If the status-quo alternative is chosen, from the remaining two options, which one would you choose? Alternative 1 ☐ Alternative 2 ☐			

Fig1: Sample choice set

C) Debriefing questions

C1	On a scale of 1 to 5, how difficult was it for you to find the choice between the cards? [1=Very easy, 2=Easy, 3=Somehow easy, 4=Difficult, 5=Highly difficult, 6=I do not know]
C2	The game that you played with choosing the preferred using the choice cards was easy to understand [1=Very easy, 2=Easy, 3=Somehow easy, 4=Difficult, 5=Highly difficult, 6=I do not know]
C3	How realistic do you think the description of the status quo (scenario C)

	[1=totally unrealistic, 2=Realistic, 3=Somehow realistic, 4=Very realistic, 5=I do not now]
C4	If you choose policy option – status quo (option C) in one of the choice sets above, could you please tell us why you are against the policy options (scenario A and B) A]. I do not believe that the alternative policy scenario would be successful B]. I do not care about inland valley's use and development in the future C]. It is the job of the government to select for us D]. I do not have information about the existing problem in the IVs E]. I do not trust government policies

D) Respondent's household details

The sample of households is those above 18 years old.

(*Household Members: *Persons who live together and eat together from the same pot (share food), including hired labor, students and spouses living and working in another location but excluding visitors)

D1.	Name of the respondent:			
D2.	Relationship of survey respondent to Household Head: (1 = household head; 2 = spouse (if household head male); 3 = other family member; 4 = other non-family member			
D3.	Age of the respondent in years:			
D4.	Gender of the respondent [0=Female,1=Male**]**			
D5.	Higher level of education completed 1; None (illiterate); 2=Primary; 3=Junior high school; 4=Senior high school; 5=Tertiary education (University and other post-secondary training colleges); 6= other (specify)			
D6.	Marital status of the respondent [1=Married living with spouse; 2=Married living without spouse; 3=Divorced/separated; 4=Widow/widower; 5=Never married			
D7.	Number of family members	Male	Female	Number of Children: (Boys/girls)
NB: Number of children (boys/girls) are those whose ages are below 12 years old				
D8.	Primary occupation of the respondent [1=Farming (crop+ livestock); 2=Salaried employment; 3=Self-employed off-farm; 4=Casual labourer on-farm; 5=Casual labourer off-farm; 6=School/college child;7=Non-school child; 8. Other, specify……]			
D9.	What is the annual total household income from rice on the farm?			
D10	Annual total household income of farm households?			

E) Social network and Infrastructure

E1	Do you currently use inland valleys for agriculture? [0= NO; 1=YES]
E2	Have you been involved in farming at the bottom of the inland valleys in the last 12 months? [0= NO; 1=YES]
E3	How many years have you been living in this village? (no of years)
E4	Do you think government support (e.g., subsidies) will be helpful or support you? [0= NO; 1=YES]
E5	Do you have access to credit services? [0= NO; 1=YES]
E6	Have you received any extension visits in the last 12 months? [0= NO; 1=YES]
E7	Do you trust the skills of extension agents working in your area? [0= NO; 1=YES]
E8	Do you have access to markets where you can sell your farm products? [0= NO; 1=YES]
E9	Farm experience (Number of years since started farming) of the respondent [ ]
E10	Mode of transport from homestead to IVs (1=Foot, 2=Bicycle 3=Motor bicycle 4=Car 5=Animal
E11	Distance to the nearest market from the residence in minutes [ ]
E12	Distance to the nearest source of fertilizer dealer from the residence in minutes [ ]
E13	Distance from the IVs to an all-season road in minutes [ ]
E14	Distance from the residence to IVs in minutes [ ]
E15	Are you a member of the farmer's association? [0= NO; 1=YES]
	Do you have access to off-farm income? [0= NO; 1=YES]

F) Attitudes and behaviors towards IV farming

FATT1	IVs farming can increase the yield of rice and other crops **[**1=Completely disagree, 2=Somewhat disagree, 3=Neither agree or disagree, 4=Somewhat agree, 5= Completely agree, 6= I do not know**]**

FATT2	IVs farming can reduce the cost of inputs (e.g., fertilizers, seed, and labor) **[**1=Completely disagree, 2=Somewhat disagree, 3=Neither agree or disagree, 4=Somewhat agree, 5= Completely agree, 6= I do not know**]**
FATT3	IVs farming can reduce the health risk of the farmers [1=Completely disagree, 2=Somewhat disagree, 3=Neither agree or disagree, 4=Somewhat agree, 5= Completely agree, 6= I do not know**]**
FSN1	Farmers in my community generally not farm IVs **[**1=Completely disagree, 2=Somewhat disagree, 3=Neither agree or disagree, 4=Somewhat agree, 5= Completely agree, 6= I do not know**]**
FSN2	Government, village chiefs, and extension agents in your area think you should farm IVs **[**1=Completely disagree, 2=Somewhat disagree, 3=Neither agree or disagree, 4=Somewhat agree, 5= Completely agree, 6= I do not know**]**
FSN3	Your family think you should farm IVs **[**1=Completely disagree, 2=Somewhat disagree, 3=Neither agree or disagree, 4=Somewhat agree, 5= Completely agree, 6= I do not know**]**
FSN4	People whose opinion you valued more recommend you farm IVs **[**1=Completely disagree, 2=Somewhat disagree, 3=Neither agree or disagree, 4=Somewhat agree, 5= Completely agree, 6= I do not know**]**
FPBC1	Do you have the capacity to farm IVs **[**1=Completely disagree, 2=Somewhat disagree, 3=Neither agree or disagree, 4=Somewhat agree, 5= Completely agree, 6= I do not know**]**
FPBC2	Can you bear the risk of participating in farming IVs **[**1=Completely disagree, 2=Somewhat disagree, 3=Neither agree or disagree, 4=Somewhat agree, 5= Completely agree, 6= I do not know**]**
FPBC3	Nothing prevents me from IVs farming **[**1=Completely disagree, 2=Somewhat disagree, 3=Neither agree or disagree, 4=Somewhat agree, 5= Completely agree, 6= I do not know**]**
FBI1	Would you like to engage in IV rice farming
FBI2	Would you like to promote inland valleys farming to neighbours?

NB: ATT=Attitude; SN=Subjective norm; PB=Perceived behaviour; BI=Behavioural intention.

G) Information on attitudinal questions towards biodiversity in the inland valleys and inland valleys use questions.

The following questions are presented to you to evaluate your personal beliefs and attitude towards biodiversity and inland valley use. There are no right or wrong answers. Please try to tell us an honest and reliable answer as you can. Each question has a scale (1-5) explaining the extent to which you agree. To what extent do you agree or disagree with the following questions? For example, the more you agree with the question, the more you select a high number. The more you disagree with what is stated in the question, the more you select a lower number. Please select one answer for each question.

G1	Biodiversity (number of trees, plants, animals) in and around the IVs is important for protection, conservation, and management. **[**1=Completely disagree, 2=Somewhat disagree, 3=Neither agree or disagree, 4=Somewhat agree, 5= Completely agree, 6= I do not know**]**
G2	Conservation and management of the biodiversity in and around the IVs are important for the livelihoods of your community. **[**1=Completely disagree, 2=Somewhat disagree, 3=Neither agree or disagree, 4=Somewhat agree, 5= Completely agree, 6= I don't know**]**
G3	The biodiversity in and around the IVs is in good condition. **[**1=Completely disagree, 2=Somewhat disagree, 3=Neither agree or disagree, 4=Somewhat agree, 5= Completely agree, 6= I do not know**]**
G4	Compared with the last 10 years, the biodiversity in and around IVs has decreased or changed. **[**1=Completely disagree, 2=Somewhat disagree, 3=Neither agree or disagree, 4=Somewhat agree, 5= Completely agree, 6= I do not know**]**
G5	Do you agree that the current generation should protect the biodiversity in and around the IVs to ensure that the future generation can continue to enjoy the benefits of the IVs? **[**1=Completely disagree, 2=Somewhat disagree, 3=Neither agree or disagree, 4=Somewhat agree, 5= Completely agree, 6= I do not know**]**
G6	Human activities (e.g., farming) within and around the inland valley have caused undesirable effects/e.g., Deforestation, water deterioration, land use conflict, water pollution, grazing conflict, and health issues in the inland valley so far. **[**1=Completely disagree, 2=Somewhat disagree, 3=Neither agree or disagree, 4=Somewhat agree, 5= Completely agree, 6= I do not know**]**
G7	Did you receive any kinds of training on the conservation and management of biodiversity in and around the IVs [0= NO; 1=YES]

G8	Did you receive any kinds of training on the good agricultural practices that help to increase your production and productivity [0= NO; 1=YES]

H) Agricultural information

H1	Do you have your own land? [0= NO; 1=YES]			
H2	Total landholding	In the local unit:	Acre:	Hectare (ha):
H3	Land tenure of total landholding (ha)	Own:	Contract/Sharecropping:	Rented:
H4	Total rice cultivated area:	In the local unit:	Acre:	Hectare (ha):
H5	The number of cropping Season:			
H6	Have you experienced any size change in the inland valley? **[**1=Expanding, 2=Shrinking,3=Fluctuating, 4=I do not know**]**			

I)Interview protocol

I1	Respondents' households' cooperation [1=Excellent, 2=Fair, 3=Average, 4=Bad]
I2	Respondent's understanding of the choice task [1=Excellent, 2=Fair, 3=Average, 4=Bad]
I3	Respondent is on a rush [1=Very rushed, 2=Somewhat, 3=Not rush]

Netherlands Research School for the
Socio-Economic and Natural Sciences of the Environment

D I P L O M A

for specialised PhD training

The Netherlands research school for the
Socio-Economic and Natural Sciences of the Environment
(SENSE) declares that

Tesfahun Alemayehu Belew

born on 28th June 1979 in Chagni, Ethiopia

has successfully fulfilled all requirements of the
educational PhD programme of SENSE.

Wageningen, 28 September 2026

SENSE coordinator PhD education

Dr Ir Peter Vermeulen

The SENSE Director

Dr Jampel Dell'Angelo

The SENSE Research School declares that **Tesfahun Alemayehu Belew** has successfully fulfilled all requirements of the educational PhD programme of SENSE with a workload of 36.7 EC, including the following activities:

SENSE PhD Courses

- A1: Environmental Research in Context (2018)
- A2 Research in context activity: 'Innovation platforms for the development of rice farming systems in the inland valleys of Côte d'Ivoire: How effective are they?' (2021)
- Approved PhD proposal (2018)

Other PhD and advanced MSc courses

- Advanced qualitative research data collection design, Wageningen University and Research (2018)
- Advanced Econometrics, Wageningen University and Research (2018)
- Theories and model in economics, Wageningen University and Research (2018)

General Skill courses

- Reviewing a Scientific Paper, Wageningen University and Research (2018)
- The Essential of Scientific Writing and Presenting, Wageningen University and Research (2018)
- Introduction to R for Statistical Analysis, PE&RC and WIMEK (2018)
- Research Data Management part 1-3, Wageningen University and Research Library (2019)
- Linear Models, WIMEK and PE&RC(2021)
- Research Ethics, Wageningen Graduate Schools (2021)
- Searching and Organising Literature, Wageningen University and Research Library (2018)

Oral Presentations

- *Optimal Land Use Scenario for African inland valleys: The Case of Cote d'Ivoire and Ghana*. CIPA kick-off workshop, 20-22 June 2018, Bouaké, Cote d'Ivoire
- *Inland Valley farming Systems: A case study of Cote d'Ivoire and Ghana*. Workshop, 9-13 September 2019, Kumasi, Ghana
- *Ecosystem Services in the inland valleys of cote d'Ivoire and Ghana: Results of the survey and focus group discussio*n. Workshop, 9-13 September 2019, Kumasi, Ghana

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