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Exploring the transition to agroforestry for smallholder farmers: a feasibility study for the Ashanti region of Ghana

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Smallholder farmers in the Ashanti region of Ghana face challenges due to shifts in climate patterns that have a significant negative impact on their crop yields. We conducted a feasibility study into the transition toward an agroforestry system by integrating trees and shrubs within crop fields. In this research, we adopted a complex systems perspective to analyse the institutional, social, and technical aspects that play a role in such a transition. By conducting in-depth analyses through three rounds of interviews and a Q-sort method with smallholder farmers in the Ashanti region, we mapped the most important challenges in transitioning to an agroforestry system. These pertain to: uncertainties in land tenure agreements, the absence of effective conflict resolution mechanisms, having no knowledge of and tools for maintaining trees, and the lack of financial resources for upfront investments. Based on our findings, we provide recommendations for the design of the transition process toward a comprehensive agroforestry system in Ghana. We recommend improving land tenure security and establishing conflict resolution mechanisms by polycentric coordination in which all stakeholders are involved for this essential institutional redesign process. To enable smallholder farmers to acquire the required skills and tools for tree crops, preferably a pilot plot for real-life demonstration is initiated. Financial resources for the smallholder farmers in the transition period need to be warranted, e.g., via the design of a carbon credit market. We recommend future research to explore the perspective and interests of chiefs/landowners in the Ashanti region who have crucial decision-making power through their land ownership.

KEYWORDS

Ghana Ashanti region, agroforestry, climate change, land tenure, agricultural training, carbon credits, livelihood assessment, sustainable agriculture

Introduction

Climate change represents one of the most urgent and pressing issues of our time, leading to significant shifts in climate patterns as a consequence of the increasing emissions of greenhouse gases (Shah et al., 2024). Human activities, including the expansion of the global economy and the reliance on fossil fuels, primarily drive these emissions. They trap heat in the Earth's atmosphere, leading to global warming. The consequences of climate change are observed across the globe, affecting the socioeconomic conditions of many communities, including those engaged in smallholder farming in the Ashanti region of Ghana, where agriculture contributes 21% of GDP (Ghana Statistical Service, n.d.).

The Ashanti region, located in the forest-savanna mosaic zone of Ghana, has a warm and humid climate due to its proximity to the equator. The climate is marked by distinct seasons. The rainy season, which occurs from April to September, is a season of abundant rainfall, encouraging lush vegetation growth. In contrast, the dry season, from November to March, is characterised by a lack of rainfall, reduced soil moisture, and an increased risk of forest fires. The region's heavy reliance on rain-fed agriculture makes it particularly vulnerable to the disruptions caused by climate change.

In recent years, climate change has intensified these climatic challenges, disrupting traditional weather patterns and leading to rising temperatures, erratic rainfall, and an increase in the frequency of extreme weather events (Comolli et al., 2024; Issoufou-Ahmed and Sebri, 2024). Such changes have had a significant negative impact on crop yields, thereby threatening the incomes and livelihoods of farmers who rely on consistent weather patterns for agricultural productivity. The erratic rainfall, in particular, has exacerbated water scarcity during the dry season, impeding the effective management of resources and the maintenance of soil moisture.

The combination of these climatic challenges and the region's growing population has resulted in a decline in agricultural productivity. In an attempt to address these challenges, farmers have increasingly resorted to the use of agrochemicals and monoculture practices. While these approaches may offer immediate solutions, they have been shown to contribute to the depletion of soil nutrients and water quality in the long term. Furthermore, the intensification of agriculture has had a detrimental impact on the region's biodiversity (Comolli et al., 2024; Dejene et al., 2022).

Consequently, those engaged in agricultural activities in the Ashanti region are experiencing increased feelings of insecurity. Income is unstable and dependent on erratic weather patterns, and current farming methods are unsustainable in the long term. Due to the limited economic resources available to them, these farmers are unable to invest in more sustainable approaches (Issoufou-Ahmed and Sebri, 2024; Acheampong et al., 2014; Darfour and Rosentrater, 2016).

One potential solution to these challenges is transitioning to an agroforestry system, which involves integrating trees and shrubs within crop fields in an agricultural method. Agroforestry has the potential to enhance soil quality, local climate conditions, pest and weed control, resilience to extreme weather, and water quality while also promoting biodiversity conservation (Addai, 2024; Comolli et al., 2024; Jose, 2009; Jose and Bardhan, 2012; Mbow et al., 2014; Vidhana Arachchi et al., 1997).

To implement agroforestry systems successfully, it is essential to gain an understanding of the local context, including climatic conditions, to ascertain their feasibility. This study assesses the potential for agroforestry in the Ashanti region, drawing on insights from interviews with smallholder farmers, experts, and stakeholders. Conducted in collaboration with the Farmerline Group, a Ghanaian company with a large network of connected farmers, this research explores the challenges and opportunities associated with adopting agroforestry practices in this region.

Theoretical framework

We adopted a complex systems perspective to obtain a comprehensive understanding of the complexities that affect implementing an agroforestry system. To this end, we employed a comprehensive methodology to investigate the complex interrelationships between the institutional, social, and technical sub-systems in the context of agroforestry adoption in the Ashanti region. This approach enables us to examine the multifaceted dynamics influencing its adoption process. By analysing these three subsystems that together form the agroforestry system, our objective is to gain a comprehensive understanding of the complexities that affect the system as a whole.

Before the empirical data collection and analysis, a literature review was conducted to establish a foundational understanding of the existing situation, examining the institutional, social, and technical subsystems. This initial phase was designed to ensure a comprehensive understanding of the current situation for smallholder farmers and to identify the key aspects that require investigation within the local context. Hence, in the following paragraphs, we start by presenting the findings from our literature review.

Institutional challenges

The term 'institutional system' describes the organised frameworks of laws, policies, governance mechanisms, and regulatory bodies that structure societal functions. These systems establish the rules and norms that govern the management of land, resources, and economic activities (North, 1991).

The most significant issue about the institutional system of Ghanaian farmers, as discussed in the current literature, is the land tenure system. A land tenure system is defined as a system of rules and regulations that govern access to land resources, including land ownership, access to land, and land exchange. In Ghana, the land tenure system operates within a complex framework characterised by legal pluralism, whereby there are various sources of formal and informal authorities governing land tenure (Obeng-Odoom, 2014). Two distinct land tenure regimes coexist: formal, documented, and registered agreements between tenant and landowner and informal, undocumented agreements. Presently, a considerable proportion of Ghanaian farmers are confronted with considerable land tenure insecurity due to the absence of formal land titles (Ibrahim et al., 2020). This absence renders farmers vulnerable to eviction and is a primary catalyst for numerous land tenure disputes (Kandel et al., 2021). Land tenure security is of critical importance to the livelihoods of Ghanaian farmers, as uncertainty in this area hinders long-term planning and restricts access to credit. This insecurity has a significant impact on farmers' capacity to invest and enhance the efficiency of their agricultural practices. Furthermore, it has important implications for adopting agroforestry systems, which require long-term investment. Since trees take time to grow and deliver value to farming activities, secure land tenure is essential for farmers to consider agroforestry as a sustainable option. Even fast-growing trees, such as cashews, take about 2 to 3 years to start yielding, according to a teacher at Ejura's agricultural college. Without long-term land security, farmers are reluctant to invest in agroforestry because the benefits may not be realised for many years (Interview Prosper Kugblenu, Ejura Agricultural College, November 1st, 2024).

Social challenges

The term 'social system' describes the network of relationships, cultural norms, and social structures that influence how individuals and communities operate. These systems shape the behaviours, practices, and decision-making processes within agricultural communities (Herder et al., 2008).

Approximately 70% of Ghana's farming population are smallholder farmers, a category of farmers defined by their limited land availability and resources (Peprah et al., 2020). Despite the gradual introduction of modern agricultural practices in the country, this transition has been significantly impeded by a dearth of financial resources, particularly among smallholder farmers (Darfour and Rosentrater, 2016; Acheampong et al., 2014). Their financial situation constrains their capacity to invest in new technologies and techniques that could potentially enhance their productivity and sustainability. Furthermore, traditional agricultural knowledge in Ghana is deeply embedded in cultural practices, which are frequently transmitted across generations (Aniah et al., 2019). Farming methods have remained largely consistent over time, with older farmers serving as the primary source of guidance for younger generations. According to Bonye et al. (2012), when faced with challenges, farmers typically seek advice from more experienced, older farmers rather than relying on formal education or external agricultural extension services. This reliance on traditional knowledge, while valuable, can also act as a barrier to the adoption of new, potentially more effective agricultural practices.

Technical challenges

The term 'technical system' describes the collective of tools, technologies, and methodologies that facilitate agricultural practices. This system encompasses the machinery, equipment, and scientific techniques that farmers utilise to effectively manage their land and crops.

The complexity of climate is a critical factor in farmers' decision-making processes, particularly in the context of Ghana, where the management of climate variability has become increasingly challenging. The phenomenon of climate change has resulted in an increase in temperatures and alterations to rainfall patterns, which have made it more challenging for farmers to predict and manage their agricultural activities (De Pinto et al., 2012; Ndamani and Watanabe, 2015). Projections for West Africa indicate that the future will be characterised by an increase in the frequency of droughts and a general trend towards drier conditions, which will further exacerbate the difficulties faced by farmers in the region (Sarr, 2012; Boko et al., 2007). Farmers in sub-Saharan Africa, including Ghana, frequently lack the capacity to adapt to these climatic changes, rendering them vulnerable to its impacts (Boko et al., 2007). In Ghana's Ashanti region, many farmers face barriers to adaptation due to limited formal education and resources, which slows the adoption of new practices (Interview Prosper Kugblenu, Ejura Agricultural College, November 1st, 2024). As indicated by the IPCC, the agricultural sector in these regions is particularly vulnerable to climate change, with the potential for significant adverse impacts on rural livelihoods and food security (IPCC, 2014). Furthermore, the continuous utilisation of conventional agricultural techniques has resulted in a sustained decline in soil fertility, exacerbating the challenges mentioned above (Nyasimi et al., 2017). This decline has resulted in a reduction in crop yields, which has led to a decline in income for farmers. Mason et al. (2015) observe that soil nutrient depletion has been a long-standing issue, intensified by the overreliance on conventional agricultural practices based on a monoculture approach. In response to these challenges, some farmers in West Africa have adopted conservation agriculture methods, such as crop rotation, to improve soil health. However, the increased use of agrochemicals while addressing immediate agricultural needs has contributed to further soil degradation (Kotu et al., 2017). These challenges highlight the necessity for implementing sustainable agricultural practices, such as agroforestry systems, to enhance resilience to climate change while improving soil fertility.

Methods

Following the literature review to analyse the current system and status of Ghanaian agriculture, we employed a qualitative case study approach, utilising in-depth interviews with farmers from the Ashanti region (see Figure 1) to gain a comprehensive understanding of the intricate local context pertinent to implementing the proposed agroforestry ecosystem. The Ashanti region has been selected as the focal area for this study due to its complex land tenure system, where much of the farmland is managed by traditional authorities. Additionally, it was chosen for its convenience, as access to the communities could be facilitated through Farmerline. The key aspects identified in the theoretical framework informed the development of interview questions for smallholder farmers in this region. Furthermore, these aspects were used to triangulate the interview

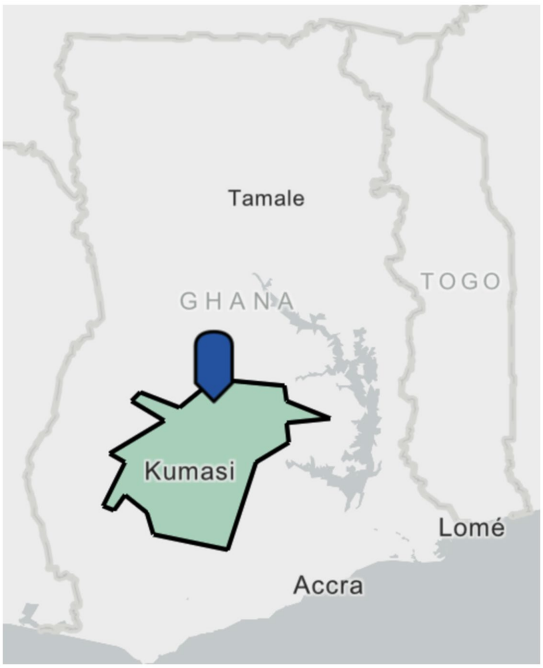

FIGURE 1
Map of the location of Ejura within the Ashanti region in Ghana, ~100 km north of Kumasi (map generated by ArcGIS).

findings, ensuring a nuanced understanding of the local context while accounting for the specific characteristics of Ashanti farmers.

The majority of the data and findings for this research come from the Ejura-Sekyedumase District to ensure a focused understanding of the local context. Located in the northern part of the Ashanti region, in the transitional zone of Ghana, Ejura experiences both high and low rainfall seasons, with temperatures reaching up to 38°C during long dry spells (Akowuah et al., 2015; Interview Prosper Kugblenu, Ejura Agricultural College, November 1st, 2024). This climate favours the cultivation of cereals and legumes, which are the main crops in Ejura, with around 70% of the population involved in their production in the region, and 85.6% in Ejura's rural areas—significantly more than the national average of 38.3% (Ghana Statistical Service, 2010; Ministry of Food and Agriculture, 2021). The size of the farming community in the region varies, with between 720 and 1,500 farmers actively involved in agricultural activities (Interview Prosper Kugblenu, Ejura Agricultural College, November 18th, 2024). Unlike other parts of the Ashanti Region, where tree crops such as cocoa, cashew and oil palm dominate, only 0.6% of farmers in Ejura engage in tree crops. Instead, the district's focus on cereal and legume farming is influenced by both its climate and land tenure system. Most farmland is owned by traditional families, which limits the long-term leasing of land to non-family members. In addition, many farmers in Ejura have migrated, 33.8% were not born in the region, from the northern regions of Ghana, where prolonged droughts drive them south in search of more favourable conditions. The majority of the working population –nearly seven in ten (69.6%)—are self-employed, with only 8.7% classified as employees. This confirms that most farmers are self-employed smallholders, farming relatively small plots of land for subsistence or small-scale commercial purposes, rather than engaging in large-scale industrial agriculture (Ghana Statistical Service, 2010). On average, each farmer cultivates around 2 hectares of land (Interview Prosper Kugblune, Ejura Agricultural College, November 18th 2024). This, coupled with the region's high poverty rate of 25% (Ghana Statistical Service, 2021), which is significantly higher than the national average, exacerbates the challenges faced by these farmers and limits their ability to adopt sustainable agricultural practices. Given these challenges, Ejura provides a challenging environment for agroforestry adoption, making it a suitable region for our study to explore the barriers to adoption.

The interviews were conducted in three distinct phases. The initial phase comprised a focus group interview conducted in the Ejura-Sekyedumase district. The focus group comprised 10 farmers from a specific farming community, which is characterised by a distinct hierarchical structure. This structure is governed by a three-person board comprising a leader, secretary, and treasurer. The leader and secretary participated in the focus group discussion. Farmerline selected the farming community based on its accessibility and willingness to participate. While this community was chosen based on its logistical suitability and the assumption that it could reflect broader regional trends, we acknowledge that the extent to which it is fully representative of other communities in the Ashanti region may be a potential limitation of the study. We reflect on this limitation in the conclusion section.

The second phase of the research involved eight in-depth interviews with individual farmers from a range of farming communities within the Ejura-Sekyedumase district. The farmers involved in the study exhibited a range of socioeconomic and agricultural characteristics (see Table 1). Six farmers were male (Farmers A, B, C, D, F, and G), and two were female (Farmers E and H). The sizes of their farmland varied significantly, ranging from 2 to 14 acres. Farmer A had the largest landholding (14 acres), while farmers F and H had the smallest (2 acres each), with an average of 6.88 acres. Most farmers grew maize and beans as their primary crops, with Farmer C also cultivating rice and Farmer H integrating mangoes alongside maize and beans. Experience with growing trees was unevenly distributed among the group. Farmers A, E, and H had prior experience with growing trees, whereas the other five farmers had no such experience. Additionally, there was a divide in agricultural training. Farmers B, C, and G had formal agricultural training, whereas farmers A, D, E, F, and H had no formal training. These characteristics highlight the diversity within the group, particularly in terms of gender, land size, crop variety, tree-growing experience, and access to agricultural education.

The objective of these interviews was to ascertain the extent to which the findings from the focus group reflected the broader community perspective. Furthermore, it was essential to ascertain the perspectives of farmers occupying diverse social positions, including those with smaller landholdings or female farmers, who might offer a more heterogeneous range of insights. The individual interviews provided a setting where participants could explore the topics more deeply. The farmers were selected straightforwardly, whereby those who expressed interest were invited to participate. In many cases, community elders facilitated the introduction to potential interviewees. While the farmers were eager to participate, it should be noted that this selection method may not fully guarantee representativeness across the broader region. We reflect on this

TABLE 1 Overview of the socioeconomic and agricultural characteristics of the eight interviewees.

	Farmer A	Farmer B	Farmer C	Farmer D	Farmer E	Farmer F	Farmer G	Farmer H
Gender	Male	Male	Male	Male	Female	Male	Female	Male
Produce	Maize, Beans	Maize, Beans	Maize, Beans, Rice	Maize, Beans	Maize, Beans	Maize, Beans	Maize, Beans	Maize, Beans, Mango
Land size (acres)	14	4	12	5	10	2	6	2
Experience with trees	Yes	No	No	No	Yes	No	No	Yes
Agri-training	No	Yes	Yes	No	No	No	Yes	No

limitation in the conclusion section. As is customary in the local culture, a small snack was offered to the farmers during the interviews.

In the concluding phase of the interviews, the primary objective was to elucidate the various characteristics of farmers that could potentially influence the implementation of agroforestry. To this end, a group interview was conducted with farmers cultivating various crops from different areas within the Ashanti region. This group interview took place during a training day at Kwadaso Agricultural College in Kumasi, Ghana, where farmers were gathered to learn about sustainable farming practices. Whereas the training did not specifically focus on agroforestry, it provided an opportunity to engage with a diverse group of farmers to gather insights relevant to their experiences and perceptions regarding sustainable agricultural methods. During this third phase of the research process, a Q-method group interview was conducted with two representatives from each of four different farmer groups, supplemented by input from a classroom of approximately 30 farmers from these groups. The objective was to ascertain the most significant factors to be considered when designing an agroforestry system. The Q-method is a qualitative research technique employed to study subjective perspectives and beliefs (Watts and Stenner, 2005). The method involves participants sorting a set of statements or factors related to a specific topic according to their personal viewpoints and has been applied in similar studies and contexts (Dugasseh et al., 2024). In this case, farmers were presented with a series of positive effects associated with agroforestry, such as improved soil health, increased biodiversity, and enhanced crop yields. They were then asked to rank these factors based on their importance or relevance to their agricultural practices. This method allowed us to uncover the underlying values and preferences of the participants, facilitating a deeper understanding of their perspectives.

This research was conducted with the assistance of Farmerline, a Ghanaian company that provides support to farmers in a variety of ways to enhance their agricultural production. Due to the extensive network of farmers connected to Farmerline, it was possible to recruit farmer participants for this study. In addition to facilitating contact with local farmers, Farmerline also facilitated access to a translator with expertise in the agricultural sector, ensuring that the farmers could provide the desired information.

Results

In this section, we present the findings from the interviews conducted with smallholder farmers in the Ashanti region, focusing on the key themes that emerged regarding the implementation of agroforestry. The results are organised according to the three sub-systems discussed in the literature review, namely the institutional, social, and technical subsystems. It is important to note that these interviews provide insights into the specific local context, which the current literature has yet to adequately address. Each theme is explored in detail to illustrate how these factors influence farmers' perceptions, experiences, and willingness to adopt agroforestry practices.

Local context—institutional system

The farmers indicated that operating within the existing land tenure system gives rise to considerable uncertainties regarding their future, largely due to informal transactions. Their farmland is officially owned by the local chief, and farmers hold annual leases with the chief, which are paid in cash. However, they have not received any official documentation that could reinforce their rights to cultivate the land. Consequently, farmers identified numerous instances where they could be prohibited from farming their designated plots and may be compelled to relocate to different farmlands in subsequent years. For those participating in this research, several factors contributed to the emergence of conflicts over land tenure.

The majority of farmers have experienced land disputes first-hand. A significant concern is the insecurity experienced by farmers cultivating land close to urban areas. The expansion of these zones frequently results in displacement from their farmland.

> *"During the construction of a prison a couple of years ago, many farmers had to leave their farmlands. They were informed on very short notice. This hinders many farmers from participating in long-term projects"—Farmer B.*

Furthermore, disputes frequently emerge from concerns related to land payments. Farmers reported instances where another individual could pay for a plot of land first, subsequently establishing themselves as the legitimate land farmer for that year.

The findings also indicate a notable lack of conflict resolution measures among farmers, particularly given their vulnerable position within the land tenure system. This absence of effective institutional mechanisms exacerbates their vulnerability, making it challenging for them to secure their rights and livelihoods in the face of ongoing disputes and external pressures.

The farmers also expressed uncertainty regarding the implications of planting trees on their farmland. While four out of eight of the farmers believed that the trees they planted would belong to them, three felt that ownership would need to be negotiated with the chief. One farmer observed that the trees would always belong to the chief. In the absence of certainty regarding ownership, farmers may be disinclined to adopt agroforestry practices, apprehending the possibility of losing both the trees and the prospective income they could yield. Furthermore, farmers noted that trees providing additional income could become sources of conflict. However, three farmers who had cultivated tree crops on their land for periods ranging from 5 to 15 years reported that they had not encountered any issues concerning the trees or the security of their land tenure.

> *"Planting trees could become a problem. Once trees start to provide revenue, the chief could make you farm another piece of land while taking the revenue from the trees, and you will have to start over again"—Farmer H.*

Furthermore, most farmers we interviewed disclosed that they had previously engaged in illicit logging activities. It was reported by half of the farmers that such activities were frequently instigated by one of the local chiefs. Most illegally logged trees are used for construction and roofing purposes, with teak being a common target.

> *"I was growing several trees on my farmland. When I went away for a week, the trees were gone when I returned.—Farmer A.*

It is also noteworthy that the responses provided by farmers to the same set of questions varied considerably. While they reported

experiencing significant insecurity concerning land tenure and gave examples of both conflicts and a lack of effective conflict resolution mechanisms, they also indicated a lack of clarity regarding potential future developments. It appeared that there was a common sentiment of unease about the possibility of future issues. Yet, there was a lack of consensus on the specific nature of these potential challenges.

The third phase of the interview process was conducted with farmers from a range of locations within the Ashanti region, all of whom were engaged in the cultivation of different crops. The objective of this subsequent phase of interviews was to gain a more profound comprehension of the particular attributes of farmers that are perceived to contribute to their tenure insecurity. The findings indicated that farmers currently engaged in the cultivation of perennial crops experience a diminished level of tenure insecurity compared to farmers engaged in the cultivation of annual crops. Furthermore, some farmers who indicated that they were part of farmer associations observed that their tenure security was more secure than that of individual farmers who negotiated with chiefs over the farmlands.

The Ghanaian government, through its Lands Commission (Salifu, 2018), and non-governmental organisations have tried to enhance the number of farmers in possession of official land tenure documents, which serve as evidence of land ownership. Nevertheless, despite these initiatives, the farmers in the agricultural communities in the Ashanti region, who are the focus of this study, lack such documentation. Thus, the results of these initiatives are inconsequential for them. Interviews with representatives of a non-governmental organisation (NGO[1]) and Ghanaian government officials from the Ministry of Food and Agriculture revealed significant differences in tenure security between the various traditional areas.

In addition to Ghana's officially designated regions, such as the Ashanti region, there are also various traditional areas, which may be situated within a single region or extend across multiple regions. These traditional areas exhibit considerable variation. In larger traditional areas, high-ranking chiefs present a significant challenge for farmers or organisations seeking to navigate complex institutional frameworks. However, these frameworks may potentially facilitate the establishment of formal land agreements. Conversely, in smaller traditional areas, there is a dearth of institutional structures to facilitate the formation of formal land agreements. Nevertheless, it may be more straightforward for parties to engage with high-ranking chiefs in these areas.

Local context—social system

The lack of access to financial resources represents a significant challenge for farmers in the Ashanti Region. This issue was identified in the existing literature and confirmed by farmers during the initial two phases of interviews. It was reported that erratic rainfall and declining yields serve to exacerbate the financial difficulties already faced by these farmers. Many farmers indicated that they lack the financial capacity to make long-term investments. Instead, they stated that they often focus on raising sufficient funds to cover land rent to avoid further jeopardizing their land tenure security. Two out of eight farmers indicated that financial difficulties represent their biggest challenge. Furthermore, the farmers indicated that procuring superior inputs, such as seeds, is already challenging under the prevailing circumstances. This suggests that the sourcing of tree seeds for agroforestry practices can present a significant barrier to participation. Additionally, the financial constraints experienced by farmers limit their access to essential machinery and tools. The farmers noted that this lack of resources hinders their ability to engage in diverse forms of farming, as they lack the necessary equipment to maintain different agricultural systems, such as agroforestry.

The farmers indicated that their knowledge is primarily rooted in traditional farming practices passed down through generations. The transfer of this knowledge plays a pivotal role in agricultural practices within farming communities. Farmers are justifiably proud of their techniques and are keen to ensure the continued viability of their current methods. Furthermore, the crops they harvest are of great significance to the culinary traditions of their communities, with all the interviewed farmers emphasising the importance of these crops in the local food culture. Less than half of the farmers, three out of eight, have undergone formal agricultural training, with the majority depending solely on traditional methods. In discussions on alternative farming methods that could enhance yields, farmers indicated interest in exploring new concepts. However, many acknowledged their lack of knowledge regarding implementing these methods.

Despite an awareness of agroforestry principles, farmers remain uncertain about the potential benefits of this approach. Many had negative experiences with trees on their farmland, citing the overshadowing of regular crops and a subsequent reduction in yields. There is a general lack of knowledge about tree maintenance, and when combined with insufficient access to machinery and tools, farmers currently appear ill-equipped to sustain an agroforestry system. For example, farmers said that they were afraid to prune their trees at all for fear that pruning would result in a loss of crop.

Local context—technical system

The farmers reported that they are currently experiencing difficulties due to climate change, particularly due to the increased unpredictability of rainfall patterns, which affect their agricultural cycles. Over half of the farmers identified this as the most significant challenge they currently face. Another concern the farmers raised is increased pests and weeds observed in recent decades. They noted that current methods of pest and weed control—most farmers now rely solely on agrochemicals—are no longer effective, leading to a significant rise in pest and weed populations that cannot be managed with traditional techniques. Consequently, this increasing reliance on costly agrochemicals further strains their financial situation and is also a significant health and environmental problem as farmers have limited knowledge of the correct use of these chemicals, such as withdrawal and re-entry periods, resulting in traces of chemicals remaining in their produce, particularly in vegetables (Interview Prosper Kugblenu, Ejura Agricultural College, November 1st, 2024).

1 Despite our efforts, we did not receive a formal consent to disclose the name of the NGO in this article.

Design of an agroforestry system

Based on our findings, we explored how the implementation of agroforestry in the Ashanti region can be stimulated by formulating recommendations for changes in the institutional, social, and technical subsystems. These are presented in the following paragraphs.

Dealing with the institutional framework

The most significant institutional challenge identified in both the literature and the interviews with farmers in the Ashanti region is the lack of land tenure security, which prevents farmers from making long-term investments in their farmland. The lack of assurance that they will be able to continue farming the same plot of land in the future acts as a significant barrier to the adoption of agroforestry practices. The initial interviews revealed that farmers lack a unified understanding of how transitioning to agroforestry would affect their tenure security and are uncertain about the implications for land ownership. Additionally, there is a lack of effective conflict resolution mechanisms to manage potential disputes.

In the context of initiating an agroforestry project with smallholder farmers, it is critical to consider the farmers who will be eligible to participate. Several factors are of significant importance when selecting Ashanti farmers for participation. These include the farm's proximity to urban development, the currently farmed crops, and the traditional area in which the farm is located.

The optimal farmer is situated in a rural area, far from urban areas, to ensure that their farmland will not be utilised for urban or infrastructural purposes in the near future. It is preferable for the farmer to have experience with tree crops rather than annual crops, as the chief is already aware of the farmer's intention to cultivate the land for an extended period. In smaller traditional areas, it is more straightforward for farmers to obtain permission to farm the land for a longer period from a chief who is in a position of sufficient authority to grant such a request. It is of the utmost importance that the project be presented to the chief first, as informing the farmers first can potentially lead to misinformation about the project reaching the chief, thereby jeopardising the project's potential for success.

Subsequently, other farmers can be included in the process once there is more understanding of the effects and risks associated with farmers participating in an agroforestry project. In the current era, the absence of formal land documents and the lack of progress by the Ghanaian government in enhancing tenure security has created a highly challenging context for farmers in the Ashanti region. For farmers engaged in or interested in pursuing agroforestry practices or for organisations seeking to establish such projects, the current lack of effective and efficient solutions to address this issue represents a significant hurdle.

Designing the agroforestry system

To guarantee the willingness of farmers to adopt agroforestry practices, it is imperative to design a socio-technical system that integrates the technical aspects of agroforestry with the social system, which encompasses the farmer's knowledge, culture, and financial capital.

In the third phase of interviews, farmers indicated that the primary motivation for transitioning to agroforestry practices is the potential for increased harvests from tree crops. This was also identified as a key factor by seven out of eight farmers during the initial interview round. The selection of tree species influences the success of an agroforestry system, but farmers may prefer other tree species than the optimal selection for obtaining additional agroforestry benefits. A subsequent point for consideration when evaluating the potential benefits of an agroforestry system is the importance of intercropping trees with existing crops. During the interviews, the farmers expressed concerns about intercropping, citing the potential for the trees to overshadow their crops and negatively impact the current yields. Seven farmers indicated a preference for cultivating trees on a dedicated field. Additionally, Farmer H, who already cultivates mango trees, expressed willingness to engage in intercropping. Their concerns show that the farmers lack the requisite knowledge on tree maintenance, such as the importance of thinning, trimming, and pruning. This type of maintenance is not typically included in their traditional agricultural knowledge base. Consequently, the system should be designed in such a way as to ensure that farmers are satisfied with the tree selection while also taking into account which trees are suitable for the Ashanti region.

Interviews conducted with the Ghanaian Ministry of Food and Agriculture and the Environmental Protection Agency revealed that the most promising tree species for agroforestry in the Ashanti region are mango, cashew, and moringa trees for farmers cultivating annual crops, and potentially cashew trees for cacao farmers. The planting of trees that can be used for construction, such as teak, is more susceptible to illegal logging practices, as evidenced by the experiences of the farmers we interviewed. The Environmental Protection Agency reiterates that intercropping is the most beneficial method.

Given the evidence that intercropping represents the most effective method of agroforestry, it is clear that there is a need for farmers to be educated in these new practices. A framework must be established to exchange knowledge between farmers who intend to employ agroforestry techniques and to maintain trees correctly. Of all the agricultural knowledge that farmers must learn, pruning is the most crucial. Interviews with farmers and Ghana's governmental agencies revealed that farmers have acquired their current knowledge through observing the actions of another farmer in real life. Demonstrating the most effective methods is the optimal approach to ensuring farmers gain the requisite knowledge to maintain trees. To this end, a dedicated field must be selected on which a party demonstrates to farmers how an agroforestry plot is maintained over its lifetime. This approach can also demonstrate the system's benefits to the farmers, which may act as a catalyst for change.

The final concern that can potentially act as a deterrent for farmers who are considering adopting agroforestry practices is the current financial constraints they are facing. A review of the literature revealed that smallholder farmers currently lack the financial resources to make long-term investments, which represents a significant obstacle to the adoption of agroforestry practices. In the course of the interviews, the farmers themselves identified financial constraints as one of the most significant challenges they are currently facing. Furthermore, the farmers indicated that they lack the financial resources to procure both seeds and saplings, as well as the requisite tools for tree maintenance. It is, therefore, evident that another party must provide support to farmers to facilitate the transition to

agroforestry. The Ghanaian government has previously implemented a project which distributed saplings to farmers. However, due to a lack of ongoing support following the distribution of the saplings, farmers were unable to maintain the trees. Consequently, the project was not deemed to be a success. Therefore, a party must assist farmers with both the financial aspect and by providing training to enable them to maintain the trees.

In addition to the Ghanaian government's provision of support, which may be motivated by an interest in Ashanti farmers' use of agroforestry methods, another option has emerged in recent years. The development of the carbon credit market has prompted numerous global entities to initiate forestry and agroforestry projects worldwide (Minoli et al., 2023; Nurrochmat et al., 2024). In these projects, a financial return can be obtained by cultivating trees, as trees can sequester carbon dioxide from the atmosphere. This additional financial incentive can serve as an extra motivation for farmers to transition to agroforestry practices. Furthermore, it could motivate third parties to make initial investments, as the carbon credit returns can serve as a business model for these entities. This would ensure their assistance with initial investments in seeds and saplings, as well as facilitate the exchange of knowledge regarding agroforestry methods among participating farmers. This option requires future research from the same comprehensive system perspective we used in our study to address the institutional, technical and social aspects of a carbon credit market. We reflect on this in the conclusion section.

Discussion

Feasibility of agroforestry in Ghana's Ashanti region

Despite the potential benefits that can be derived from implementing agroforestry methods, such practices remain uncommon in Ghana's Ashanti region. There are several principal reasons why this has not yet been implemented.

A review of the literature on the general context revealed that farmers are experiencing difficulties in making long-term investments due to the limited security of their land tenure. The farmers who participated in the study explained that they lack documentation regarding lease and land ownership. They also stated that their short lease terms of 1 year do not allow them to make investments for future years. Furthermore, the farmers indicated that they are not in a position to engage in conflict with local landowners and that there are no apparent conflict resolution mechanisms.

Additionally, farmers encounter constraints in their knowledge of agroforestry and in accessing financial resources. The current farming practices are based on traditional methods handed down through generations. The strong farming culture, which is closely tied to crop selection and local food traditions, presents a significant challenge for farmers when attempting to adopt agroforestry practices that involve different methods and new tree or plant species. Despite their interest in learning new agricultural techniques, farmers' lack of formal education makes them reluctant to adopt intercropping trees. Experiences have demonstrated that when trees overgrow their fields, it can have a negative impact on regular crops. This highlights the need for targeted training and capacity-building initiatives, particularly in teaching farmers proper thinning, trimming, and pruning techniques to ensure effective tree management without compromising crop yields. Furthermore, farmers often lack the financial resources to purchase and maintain saplings, as well as to acquire the tools needed for the upkeep and pruning of agroforestry trees. This highlights the necessity for initiatives that provide financial support to assist farmers in covering these essential costs when transitioning to agroforestry practices.

Conclusion

In our study, we adopted a complex systems perspective in which we analysed the institutional, social, and technical challenges that need to be overcome for a transition to sustainable agroforestry ecosystems. In their agroforestry experimental pilot study in Argentina, Comolli et al. (2024) show that such ecosystems enhance resilience to extreme weather events better than monocultures. Their pilot demonstrates that an agroforestry system can lead to moderate temperatures in the system, the retention of moisture as well as to fewer detrimental insects, leading to an increase in biodiversity (pp. 10–11). Our complex system perspective extends such pilot studies by looking at the local context in which the transition needs to be actualized by the local farmers. Our comprehensive analysis enables us to translate the challenges into the following recommendations for implementing an agroforestry ecosystem in Ghana.

First, farmers in Ghana's Ashanti region are unlikely to initiate bottom-up initiatives to transition to agroforestry practices; they need support to navigate the institutional challenges they face. The land tenure system appears to be the most significant challenge. Hence, we deem an increase in tenure security for farmers in Ghana a top priority. To this end, cooperation between smallholder farmers, the chiefs/landowners, relevant NGOs, or a third party as an intermediary stakeholder, and the Ministry of Food and Agriculture needs to be established. This reflects Elinor Ostrom's concept of polycentric coordination for common goals "to arrive at collaborative solutions that best fit the needs and properties of their action arenas" (Desrochers and Szumak, 2020, p. 145) rather than "a reliance on solutions imposed coercively from above" (ibid, p. 146). For this institutional redesign, a process design is needed to involve all relevant actors and to address the informal institutional environment (such as the local culture, norms and values; Koppenjan and Groenewegen, 2005).

Second, our study shows that capacity-building initiatives and training for growing and maintaining trees in an intercrop setting, as well as financial assistance, are required during the initial stages of adopting agroforestry practices. In interviews, farmers indicated that while the government attempted to provide saplings, these efforts yielded limited success because other identified issues were not adequately addressed. Although pilot studies such as those reported by, amongst others, Comolli et al. (2024) take an extended period of time, they can be used to demonstrate the advantages and the selection of a most suited agroforestry ecosystem for the local context. Such a pilot may also convince smallholder farmers and chiefs of the feasibility of agroforestry. And it can be used for training the required skills.

Third, given the required financial support in the start-up phase, we recommend the exploration of the potential benefits of utilising the

carbon credit market. The distribution of carbon credit funds can serve as an incentive for farmers to participate by generating an additional revenue stream. The underlying principle is that agroforestry contributes to carbon storage and thus yields carbon credits, which can be bought by companies that want to compensate for their carbon emissions in their production process (Anjos et al., 2022; Kreibich and Hermwille, 2021). This can assist the above-mentioned third party in covering the costs associated with addressing the institutional, social, and technical challenges faced by the farmers. Furthermore, this approach can provide a viable business plan for the third party, enabling them to generate revenues while supporting farmers in their transition to agroforestry. Several efforts have been made to promote such practices in Ghana. For instance, the promotion of agroforestry practices as carbon sinks and a good base for income diversification is part of the REDD+ strategy developed by the United Nations Framework Convention on Climate Change (UNFCCC) in 2008 to foster climate mitigation (Ghana REDD Strategy, 2016). The 'Climate-Smart Agriculture Investment Plan for Ghana' by the Worldbank (2024) also considers agroforestry to be a promising climate mitigation technique as it has a positive impact on heat- and drought-tolerance, disease resistance, and soil fertility management.

Two examples of such projects are the ACORN initiative of the Dutch bank Rabobank, which is in the Kintampo, Techiman, Wenchi, Bole, and Sawla districts in Ghana in collaboration with the Ghanaian Ministry of Food and Agriculture (Rabobank, 2024). And in the fall of 2024, an agroforestry initiative was started near Kumasi; the 'Farm of the Future' (FoF) project, led by the organization reNature which aims to support 100 farmers with an additional revenue stream by utilizing carbon credits (ReNature, 2024).

Evaluations of projects to offset carbon emissions linked to agroforestry in Ghana have been conducted. For instance, Lee (2012) analyzed four agricultural carbon projects in the Northern and Western regions of Ghana that were led by the Rainforest Alliance, A Rocha Ghana, CARE International, and PARED and emphasized the potential for such carbon projects if those projects were able to effectively access the carbon market and address the high transaction costs involved and methodology issues that come with monitoring carbon. The Danish International Development Agency has funded an agroforestry project 'CLIMCOCOA', whose evaluation, among other things, concluded that context-specific socioeconomic and biophysical factors should be carefully taken into account to maximize the potential of agroforestry and avoid unintended social and environmental consequences. Another conclusion was that land and tree tenure need to be aligned with farmers' indigenous practices. They did not yet find sufficient clarity on key issues that come with the development of a fair and transparent benefit-sharing scheme that utilizes carbon credits in the promotion of agroforestry (Olwig et al., 2024).

Other potential revenues from agroforestry in Ghana have been explored as well. A study on agroforestry with farmers around Kakum National Park in the Central Region reveals an additional revenue income through sales of fuelwood made from the branches of the trees (Arhin et al., 2020). Another study on eight agroforestry farms in the Nandom Municipality in the Upper West Region of Ghana shows that farmers may have a specific preference for the tree type to be integrated with the crops. Some species are not conducive to crop productivity, whereas others are even giving multiple economic uses in terms of, e.g., food additive or medicinal value (Benebere et al., 2023). Furthermore, a study by Addo-Danso and Amankwaa-Yeboah (2022) explains how bamboo-based agroforestry systems can contribute more to crop productivity and improve soil fertility and pH levels when compared to monocropping systems. A comprehensive approach to assess the mix of potential sources required for financial support in the start-up phase of agroforestry by smallholder farmers in Ghana is needed.

Future research

Our study also contains limitations due to the choices in our research design. To address these limitations, we offer the following topics for future research.

First, this research was conducted with the invaluable assistance of smallholder farmers, governmental entities, and an NGO. Nevertheless, to more effectively address the current land tenure situation and the potential impact of agroforestry on the land tenure insecurity of farmers, the insights of chiefs within the Ashanti region are essential, as they are the primary stakeholders in the acquisition of land tenure agreements and related documentation. In addition, we selected the Ashanti region in Ghana based on its logistical suitability and the assumption that it could reflect broader regional trends. Still, other regions need to be analysed to assess and contribute to the generalisability of our findings.

Second, not addressed in our study is the role that indigenous knowledge can play in the transition to agroforestry, as explored by Ogunmekan et al. (2024), who study "the viability of a combination of the traditional beliefs and cultural ethos with ecological projects, in achieving … sustainable development goals" (Ogunmekan et al., 2024, p. 1). Such an analysis is an extension of the analysis of the social sub-system. It can provide deeper insights into the social fabric of small farmer communities that may be influenced by or influence the transition to an agroforestry ecosystem.

Third, a study into the complexities of the carbon credit market and the prevailing Ghanaian regulations on carbon market projects can be conducted. This study can assess whether utilising the carbon credit market to establish agroforestry projects is a viable option. The distribution of carbon credit monetary returns to fund the system needs to be included, e.g., to assess whether monetary returns from the carbon credit market can be employed to secure land agreements with traditional authorities. A more in-depth study into the contextual success factors of using the carbon credit market and additional revenues to stimulate the adoption of agroforestry is needed to assess the potential for large-scale implementations, also after the start-up phase.

Lastly, we recommend the study by Taillandier et al. (2023) entitled "Growing Resilient Futures: Agroforestry as a Pathway Towards Climate Resilient Development for Smallholder Farmers," which was published after the completion of our research project. Taillandier et al. used the Climate Resilient Development Pathway framework, focussing on creating concrete pathways to agroforestry adoption in the Global South. Their framework presents a tool for the establishment of agroforestry projects to provide support to smallholder farmers on a global scale.

Reflection on the position of a European researcher in a local context

The involvement of a European researcher in the Ghanaian context revealed a complex interplay of cultural differences. While Ghanaians

expressed enthusiasm for engaging in the research, on occasion, interviewees provided responses that they believed to be aligned with the research objectives or answered without fully grasping the question. Subsequent discussions yielded different responses when farmers were afforded more time to consider the questions carefully. Furthermore, interviews with farmers were conducted with the assistance of a translator proficient in both local languages and English, as well as in agroforestry systems. Still, the necessity of translation introduced a layer of complexity, which may have influenced the empirical data.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Human Research Ethics Committee (HREC), Delft University of Technology, the Netherlands. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

YD: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. JU: Conceptualization, Methodology, Supervision, Writing – review & editing. EA: Conceptualization, Methodology, Supervision, Writing – review & editing. LK: Conceptualization, Resources, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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