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Agroforestry-based community forestry as a large-scale strategy to reforest agricultural encroachment areas in Myanmar: ambition vs. local reality

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Abstract

Key message The Forest Department strongly influences agroforestry design, tree species selection, and the participation and motivation of farmers to plant trees. Farmers perceive trees as harmful to crops and have avoided planting them near crops. We recommend considering farmers' preferences, establishing farmers' field schools, and increasing their awareness about the benefits of trees to improve adoption rates of agroforestry systems.

Context The high rate of deforestation in Myanmar is mainly due to agricultural expansion. One task of the Forest Department is to increase tree cover in the agricultural encroachment areas by establishing large-scale agroforestry-based community forests (ACFs).

Aim The objectives of this study were to analyze the adoption and performance of the ACFs in the agricultural encroachment areas in the Bago-Yoma Region, Myanmar; and to provide recommendations to enhance the adoption of ACFs by farmers.

Methods We inventoried 42 sample plots and surveyed 291 farmers. Survey responses were analyzed by binary logistic regression, one-way ANOVA, and non-parametric correlation tests to evaluate factors influencing the adoption of ACFs. Stand characteristics were calculated from the inventory data to evaluate the performance of ACFs.

Results Our results show that farmer participation in ACFs was lower than stated in the registry of the Forest Department. Farmers practiced four different agroforestry designs in ACFs with different outcomes. The Forest Department strongly determined tree species and planting designs, farmers' perception and participation in ACFs. Farmland size, unclear, and insufficient information on ACFs, and a negative perception of raising trees in crop fields were the major factors limiting the adoption rates of ACFs.

Conclusion We recommend capacity building for farmers and Forest Department staff and raising awareness about the benefits of planting designs and trees on farmland. A stronger consideration of farmers' preferences for design and species selection could increase their motivation to adopt ACFs and improve the long-term sustainability of ACFs.

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This article is part of the topical collection on Socio-ecological conflicts in forest management: risks of (not) adapting?

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Keywords Agricultural encroachment, Agroforestry, Forest governance, Perception, Deforestation, Degraded forest

1 Introduction

Deforestation is a major issue worldwide, as it contributes to climate change and land degradation (FAO 2020). Its impact has been severe between 2010 and 2020 (FAO 2020; Hoang and Kanemoto 2021; Vancutsem et al. 2021), when the world lost a net total of 4.7 million ha of forests annually, predominantly in the tropical regions (Keenan et al. 2015; FAO 2020). Deforestation in tropical countries was driven mainly by the conversion of forests to agricultural land, including commercial and subsistence farms (Keenan et al. 2015; Curtis et al. 2018). Many governments, especially in South East Asia, have been looking for sustainable solutions to manage and reforest agricultural encroachment areas and settlements in state forests (Iftekhar and Hoque 2005; Bhusal et al. 2018; Yurike et al. 2021).

Myanmar's forests cover 42.9% of the country's total area, and between 2010 and 2020, it was ranked seventh among the top 10 countries with high rates of deforestation in the world ($-2900\ km^2$ per year) (Reddy et al. 2019; FAO 2020). Agricultural expansion has been the main cause of deforestation in Myanmar, where 74% of the areas that were deforested from 1988 to 2017 became agricultural land (Lim et al. 2017; Yang et al. 2019; Naing Tun et al. 2021). Aside from the agricultural expansion of mostly small-scale farms, other underlying reasons for Myanmar's failure to protect forests from deforestation and degradation include large-scale logging, agricultural concessions, illegal timber extraction, corruption, inadequate staffing at the Forest Department (FD), and poor law enforcement by the FD (Erni 2018).

Fifty-nine percent of Myanmar's total forested area are state forests, which cover 25.5% of the country's total area (FD 2020). The FD headquarter is in charge of monitoring and administration on the national level, while regional FD offices are in charge of implementing the forest management plans (FD 2020). Agricultural expansion in state forests has been illegal and strictly prohibited since the adoption of the Forest Law in 1992; however, forest encroachment by settlements and agriculture amounted to 740,100 ha (i.e., 5% of the total state forest areas) by the year 2013 (FD: Encroachment data in Permanent Forest Estates, unpublished). Since 2013, the FD has increased its efforts to reduce agricultural expansion in state forests and reforest deforested areas (FD: Resettlement plan for encroaching households, unpublished; President's Office: Instructions no. 13(1)/7, unpublished).

Different strategies and goals have been implemented in various countries to reforest farmland (Harper et al. 2017; Yue et al. 2020). Among these, agroforestry has been promoted as a sustainable land use approach that addresses the reforestation of agricultural land as well as a climate change adaptation and mitigation strategy that can fulfill both the ecological and socio-economic needs of farmers (Nair 2013; Bezerra et al. 2019; Nyong and Martin 2019; Tubenchlak et al. 2021; Abbas et al. 2021). Although definitions may differ in many aspects, the concept of agroforestry generally involves the introduction and management of trees in different spatial or temporal arrangements on farmland (Atangana et al. 2014a).

To achieve the government's official goal of sustainable land use by increasing tree cover while ensuring the livelihood of local people, the Myanmar FD opted to let farmers plant a minimum of 150 trees per acres (375 trees per ha) in encroached forest land, rather than taking legal actions against them (FD, Resettlement plan for encroaching households, unpublished). This decision took into consideration that many farmers had been farming these areas for generations (FD, Resettlement plan for encroaching households, unpublished). The framework of the program is based on the national "community forestry instructions" and a community forest land title is given to farmers that have established agroforestry areas in the encroaching agricultural areas (FD, Resettlement plan for encroaching households, unpublished; FD 2018). In regular community forests (CFs), trees are planted on communal land and involve collective action and benefit-sharing. In contrast, in the agroforestry approach, farmers are required to plant trees on land that is perceived to be their property, and all decisions are made individually by each farmer (FD 2018). Here, we take into account the officially set national name of "community forestry" while highlighting the actual agroforestry nature of the reforestation approach, and thus the term "agroforestry-based community forests" (ACFs) will be used to differentiate it from regular CFs.

Farmers that have received their community forest certificates can obtain an official, 30-year land lease with associated land use rights, including access, withdrawal, management, and exclusion rights except alienation rights for the area designated as ACFs (FD 2018). The FD is responsible for monitoring and following up on the status of those ACF areas and can revoke the certificates of ACFs that are not working well (FD 2018). Previous studies have shown that the participation of farmers in reforestation programs can be increased if land use rights are secured and provided as an incentive (Soe and Yeo-Chang 2019). However, ACFs have only been implemented by the FD in Myanmar on a large scale and in a top-down manner since 2013, mainly as a tool to increase tree cover in agriculturally encroached areas of state forests. Therefore, the efficiency of the program, as well as the levels of participation, motivation, and implementation by the farmers remain unclear. Even though the long-term success of this approach is unclear, the current ACFs have been implemented on a nationwide scale (FD, Resettlement plan for encroaching househlds, unpublished). Therefore, in this study, we aimed to assess the levels of farmers' participation in, and performance of, the ACFs. Specifically, we aimed to understand the factors that drive the participation of farmers in ACF; identify the ACF designs that are practiced, as well as the factors that influence ACF design and species selection; and investigate tree survival and stand characteristics of different ACF designs.

This study provides insights that can be applied to other encroachment areas throughout Myanmar as well as other countries (e.g., Indonesia, Nepal, Ghana) facing similar challenges associated with the encroachment of agricultural areas into state forests (Bhusal et al. 2018; Yurike et al. 2021; Acheampong et al. 2021).

2 Materials and methods

2.1 Study site

This study was conducted in the Taungoo district, which is part of the Bago mountain range (Bago-Yoma) in the Bago region in central Myanmar. During the last decades, the Bago-Yoma has lost around 0.5% of its forests each year and the main contributors to forest disturbance in the region have been illegal logging (59.8%), water invasion due to dams (14.6%), forest clearance for the establishment of plantations (8.4%), encroachment due to farming (10.4%), and settlements (6.8%) (Kant et al. 2014; Shimizu et al. 2017). Illegal logging was mainly through selective logging with elephants, resulting in qualitative forest degradation; however, deforestation and long-term land use changes have been mainly due to flooding, agricultural encroachment, and settlements (Shimizu et al. 2017). The study area is predominantly dry, mixed deciduous forests with commercially important trees, such as teak (*Tectona grandis*

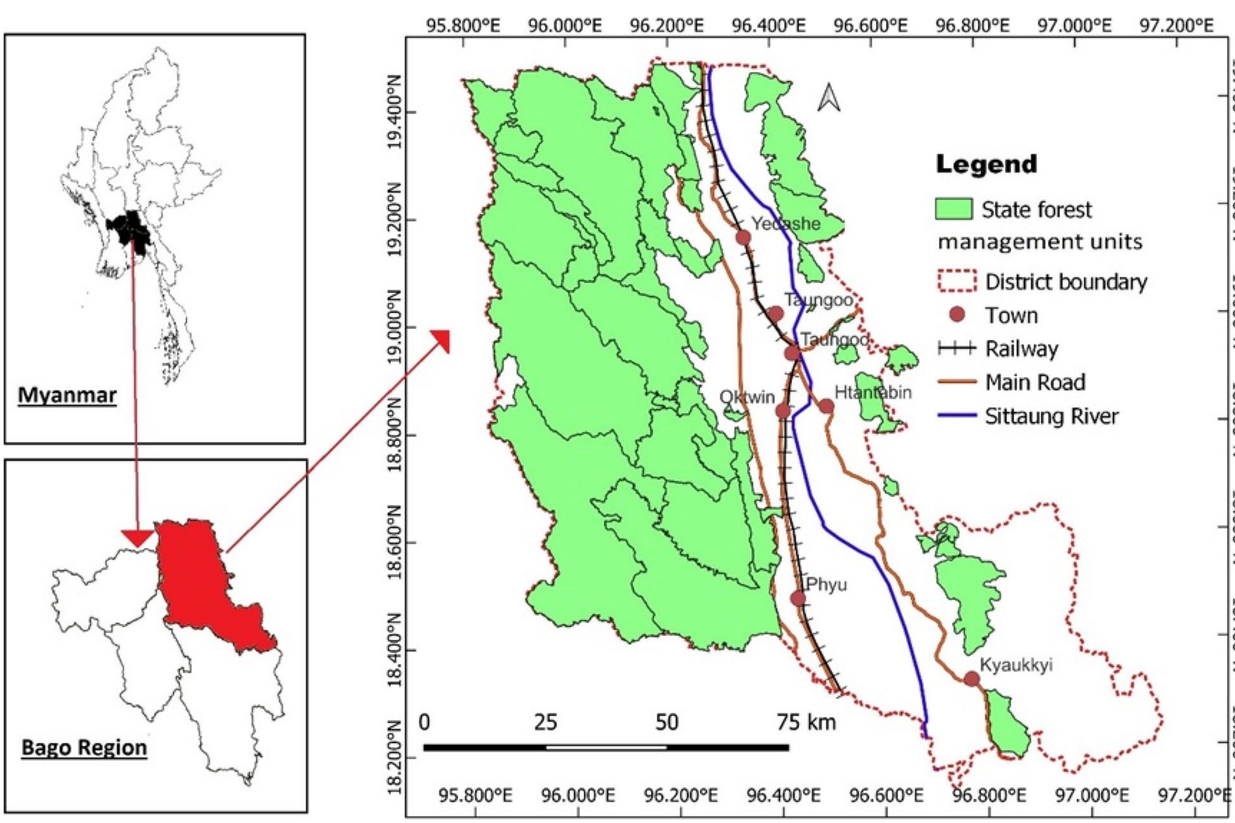

Fig. 1 Location of the study area, Taungoo district within Myanmar

L.), *Xylia xylocarpa* R., and *Pterocarpus macrocarpus* K. (FD 2015). The total area of the district is 10,677 km^2, of which 52.4% comprises state forests. The state forest area is divided into 42 reserved forests and two protected public forests (see Fig. 1). The mean annual rainfall is between 1400 and 2400 mm and the mean temperature is 27 °C (FD 2015). The district was selected as the study site not only because of its ecological significance but also because it is considered a hotspot for agricultural encroachment (11,153 ha in 2016) as well as an area undergoing high rates of ACF establishment in the agricultural encroachment area (FD 2015). Figure 2 shows the areas with established regular CF and ACF in the study site. A total of 4640 ha of CFs have been implemented in the study site, of which 96.4% are ACFs in agricultural encroachment areas. The FD started the implementation of ACFs in the study area in 2015 and it continued the implementation with yearly targets (Fig. 2) (FD 2015). According to FD data, a total of 2409 households had participated in the implementation of ACF by the end of 2019 (FD, Community forest establishement data, personal communication, July 16, 2020).

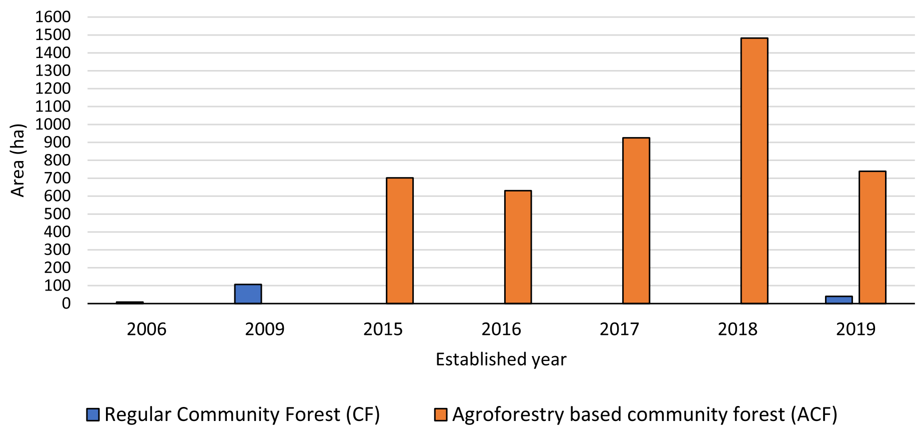

Fig. 2 Regular Community Forest (CF) and Agroforestry-based Community Forest (ACF) establishment in the studied district each year (data source: Forest Department, Community forest establishment data, personal communication, July 16, 2020)

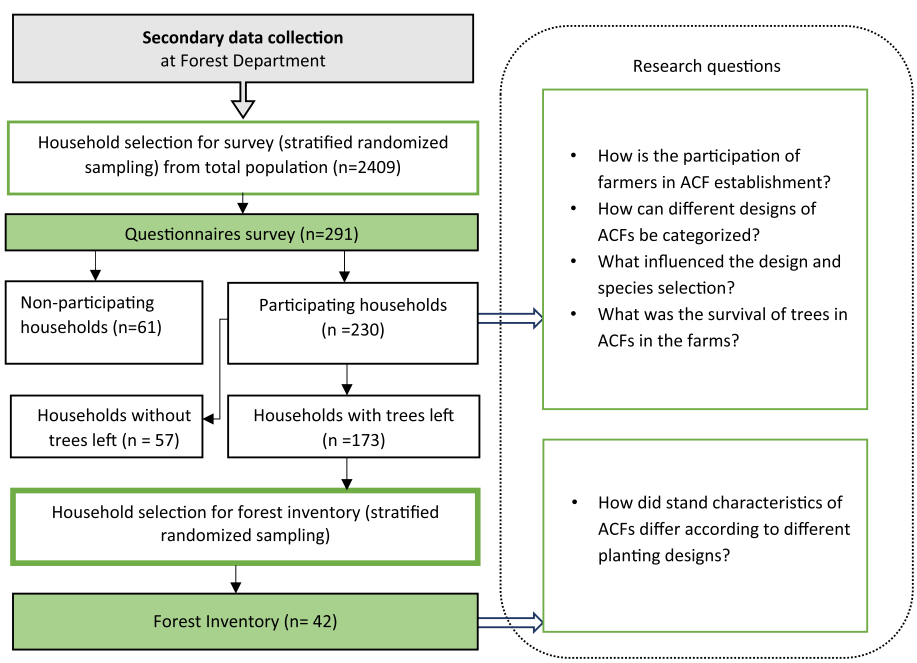

Fig. 3 Methodological flow of the study

2.2 Data collection

The mixed-method approach we employed in this study included a forest inventory and a survey followed by open questions and semi-structured interviews. Information related to the ACF establishment was first collected from the FD. The methodological flow diagram is presented in Fig. 3.

2.2.1 Questionnaires, surveys, and interviews

Sampled households were selected from among those registered as ACF members using a disproportional stratified random sampling method applied to different townships and ACF establishment years (2014–2018). The required sample size was calculated according to Desu and Raghavarao (1990) and Hahn and Meeker (1991) using NCSS software (NCSS 2020). Out of a total population of 2409 households who are registered at FD as ACF members, a sample size of 291 households was selected, producing a 90% confidence interval with a margin of error of ± 0.027 for an estimated proportion of 0.10. Household heads or other adults living in the same household were selected as interviewees, depending on their availability. Around 25% of the interviewees were female, and 75% were male. The survey was conducted in July and August 2020. In addition to survey questionnaires, we asked all sampled households open-ended questions (e.g., reasons of participation) during the survey to gather additional qualitative data and contextual information.

2.2.2 Forest inventory

Households without ACFs were excluded from the forest inventory sampling. To assess the forest conditions of established ACFs, we performed a forest inventory. First, we selected at least 24% of households with ACFs, using a stratified randomized sampling method. Then, a total of 42 plots measuring 20×20 m from different ACF designs were assessed during the forest inventory. The size of the sample plots were commonly used in previous forestry research in Myanmar (Aye et al. 2011; Oo and Lee 2012). For all the trees measuring ≥ 5 cm diameter at breast height (DBH) within the sample plots, we identified their species and recorded their DBH.

2.3 Statistical analysis

We applied descriptive statistics to summarize the survey results. To assess the influence of factors on participation in ACF, we employed binary logistic regression analysis. This analysis evaluates the association between the dependent and independent variables when the dependent variable is binary (Harrell 2015). We considered participation as a binary and dependent variable, and therefore, the analysis was carried out to reveal whether the independent variables (i.e., household characteristics and knowledge level about ACF) influenced participation in ACF.

We used one-way ANOVA to compare the household characteristics among ACFs of different designs. This analysis evaluates the differences among three or more groups. ANOVA was followed by post-hoc tests to determine which groups differed significantly from the others.

We evaluated the association between the “designs instructed by the local FD” and the “designs that households practiced” through a Pearson chi-square test. This test is commonly used to check if non-parametric categorical data are statistically related or independent when the dependent variable is nominal (Nihan 2020). All descriptive statistics and statistical analysis of survey responses were performed using Stata/IC 16 software (StataCorp 2019). The detailed dataset and the commands used in the analysis can be found on the Zenodo platform (San et al. 2023).

For the data analysis of the forest inventory, we first calculated the average number and basal areas of trees per hectare for ACF forest plots without including cropping areas using Microsoft Excel. During interviews, farmers usually claimed that their farmland is divided into cropping areas, forested areas and fallows. As the original goal of the FD was to let farmers plant a minimum of 375 per ha of their agricultural encroachment areas, we need to consider trees per total farmland areas by including all cropping areas, fallows and reforested areas. Hence, to compare the inventory results with the FD’s goal, we additionally calculated ‘trees and basal area per ha of total farmland’ by including all types of farmers’ land which are perceived as their property.

2.4 Classification approach

Agroforestry systems need to be classified to evaluate the performance of different designs (Nair 1987). Several methods and approaches have been discussed and applied throughout the past decades (Sinclair 1999; Torquebiau 2000; Atangana et al. 2014b). Sinclair, for example, (Sinclair 1999) proposed a classification approach based on the agroforestry practices and the predominant usage of the land (e.g., livestock and trees, trees in farmland, or multipurpose woodlot) as well as the spatial arrangement (e.g., lines or groups), density (number of trees per hectare), and diversity of tree components (e.g., monoculture or mixed species). This approach enables the detailed and specific classification of agroforestry practices, focusing on the functional and structural arrangements of trees.

Therefore, we adopted the classification approach of Sinclair (1999) in this study, although we adapted the approach based on field observations of the different agroforestry practices in the study area. Because of the lack of diversity of planted tree species, which are mostly teak and eucalyptus (*Eucalyptus camaldulensis* D.), we categorized ACF practices based on the types of vegetation within two categories, namely "Tree planting without natural forest remnants" and "Natural Forest remnant-based practices." Under the first practice, we differentiated two design categories based on tree structural arrangements, namely (A) boundary planting and (B) woodlot planting (i.e., in plots). Under the "natural forest-based practices" category, we designated (C) planting trees in degraded forest remnants, and (D) protection of degraded forest remnants as different design categories.

We define "boundary planting" (category A) as planting trees at the border of the farmland in one or two rows of trees. Because the farms in the study site were often irregularly shaped, the trees under this category are in irregular lines along the farm border.

We define "woodlot planting" (category B) as planting trees in plantation plots without mixing with existing natural vegetation or crops. The establishment procedures for these two categories included clearing the land by cutting all existing vegetation.

We define "planting trees in degraded forest remnants" (category C) as planting trees in degraded natural forest patches situated near cropping areas. Households under this category have non-agricultural areas such as fallow forests or secondary forests on the hills next to their farms. These forest remnants are legally owned by the state, however, farmers with forest remnants around their farms have informally acquired these remnants as their property, with neighbors usually recognizing the informal land tenure.

Finally, we define "the protection of degraded forest remnants" (category D), as the protection of a degraded forest and registering it as an ACF without planting new trees. Similar to farmers in category C, those under category D have degraded forest remnants around their farms which are recognized locally as their property, despite their original legal status as state forests. In comparison to category C, farmers in category D did not plant any trees in the remnants and only reported protecting them as ACFs.

3 Results

3.1 General characteristics of the households

On average, farm households have a household head aged 50 years, with a household size of five persons, of which three are working on 4.5 ha of land, generating an annual income of 2465 USD. Sesame, groundnuts, and rice are the main crops grown in the study area. The majority (79%) of households rely purely on agriculture, while 19% have other income sources. The remaining 2% depend exclusively on off-farm income. The majority of household heads (92%) have only been educated up to the primary school level or via monastery education (i.e., monks teach farmers how to read and write).

3.2 Participation in ACFs

All interviewed households ($n = 291$) were registered as ACF. According to the FD, all registered farmers participated in ACF implementation; however, our results showed that only 79% implemented ACF in their farms. Among participating households, the majority (57%) of participants stated that the only reason they established ACFs on their farm was to follow the local FD's instructions. Forty-three percent of participants were driven by their inherent motivation. Among these, 36% cited the main reason for participation was to gain timber, bamboo, and firewood; 3% participated to secure land rights; around 2% expected to receive monetary income; 2% participated due to the influence of neighbors; and the remaining 1% stated other reasons such as a desire for shade during summer or to engage in ACF as a hobby.

Among 21% of total households who did not participate in ACF establishment on their farmland, we asked for their reasons for not participating. The majority of farmers (20%) provided no specific reasons and only stated that they were unwilling to plant trees on their farms. Because this topic is sensitive and sometimes complicated for some farmers, we did not ask for further elaboration. Another 20% of farmers stated their main reasons for non-participation was a lack of information about ACF. An interviwee explained that "I do not know I was registered as an ACF user group member. I remember that FD gathered villagers to attend a seminar once and I was there just to listen to their talk. I do not even have any farmland here in this village." (Participant 247/ACF member/village head, personal communication, August 19, 2020). Another interviewee responded that "I do not understand why my name is registered as the ACF user group chairman. I am a machine repairing expert and work at a workshop. I am not a farmer or do not have farmland." (Participant 14/ACF member/village head, personal communication, July 30, 2020). This group of farmers included those that did not know that they were listed as an ACF member, those that did not know that they had to plant trees, and those that did not know how to plant trees. Other stated reasons were insufficient land to plant trees (16%), insufficient labor and capital (13%), interference of trees with crops (10%), dispute with the FD (10%), insufficient seedling supply (5%), and others (7%).

Binary logistic regression between participation and explanatory household variables, including demographic and socio-economic factors, and knowledge about ACF

Table 1 Results of the binary logistic regression analysis

Variable	Unit	Mean of non-participating households ($n=61$)	Mean of participating households ($n=230$)	β	*P* value	Standard error
Total land size	ha	3.5	4.7	0.139	0.025*	0.062
Annual income	USD	2262	2519	0.000	0.503	0.000
No. family worker	Persons	3	3	−0.141	0.514	0.216
Age of Household-heads	Years	47	51	0.004	0.802	0.017
Household size	Persons	5.2	4.8	−0.192	0.198	0.149
Education of household-**head**	Level	1.1	1.1	−0.654	0.187	0.496
Knowledge on ACF	Level	2	3	2.897	0.000**	0.362

Education: *level 1* = primary, *2* = secondary, *3* = high school and *4* = higher education, Knowledge on ACF (Agroforestry Community forests): *level 1* = no knowledge, *2* = little knowledge, *3* = moderate knowledge, *4* = good knowledge

* $P \leq 0.05$, significant; ** $P \leq 0.01$, strongly significant

was carried out to evaluate the relationship between the reported reasons and participation and non-participation in ACF. The regression model was statistically significant ($\chi 2 = 117.29$, $p < 0.01$). Among demographic factors, annual income, number of workers per household, household size, age, and education of household heads did not significantly influence farmers' participation. This finding contradicts the farmers' statements that insufficient labor was the reason for not participating. The only variables with a significantly positive impact on the adoption of agroforestry were the total land size of farms ($\beta = 0.14$, $p < 0.05$, Table 1) and the information provided to the farmer about ACF ($\beta = 2.89$, $p < 0.01$, Table 1), indicating that sufficient land size and knowledge about ACF positively impact farmers' willingness to participate in ACF.

In summary, the adoption of ACF by most farmers was driven mainly by the pressure from the FD on the farmers. Among non-participants, most reported not liking planting trees, lack of information, and insufficient land as the main reasons. The latter two points, the lack of information transfer from the FD and total land size, were statistically supported by binary logistic regression as influencing factors to participation.

3.3 Implementation and motivation for the specific agroforestry practice

The survey reveals that most participating households planted only eucalyptus and teak trees in their ACFs. Households who planted only eucalyptus were around 36% of the participating households while only teak was planted by 29%. Around 10% of households planted both eucalyptus and teak while the rest 25% planted two or three species in different mixtures. Although Community Forestry Instructions give farmers the right to develop their management plan for ACFs as well as to select their preferred species and designs, it was found that FD selected and distributed specific tree species without considering farmers' preferences.

Among the ACF designs, the majority, 37% of participating farmers, adopted Category B, "planting trees as woodlots," followed by category A, "boundary planting" by 33% and Categories C and D, i.e., "planting in degraded forest remnants" and "protection of degraded forest remnants" by 11% and 10%, respectively. The remaining 9% of participating farmers adopted a mixture of two or more categories, and we excluded them from the subsequent characterization of each design category. Only households belonging to a single ACF design category were compared.

The analysis of the reasons for adopting the different agroforestry design categories is shown in Fig. 4. The majority (39% and 43%, respectively) of farmers who adopted categories A and B stated their main reasons for selecting the specific designs were to follow the FD's instructions. Another main reason for adopting these two design categories was to avoid trees shading their crops, which they perceived as a disturbance to crop production. The availability of unused land or non-arable land on the farm was a major reason cited by 26%, 32%, and 38% of farmers for adopting ACF design categories B, C, and D, respectively, where woodlots are outside the cropping area. The abovementioned reasons reflect the desire of farmers to avoid growing trees in their cropping area, but rather establish ACFs outside the cropping areas.

Apart from the shared reasons mentioned above, farmers reported specific reasons for each design category. Specifically, farmers (20%) from Category A adopted the respective design to demarcate the borders of their farmland (Fig. 4); farmers (10%) from category B selected the design as a strategy to more easily manage weeds and fire protection; farmers (32%) from Category C adopted the design to combine newly planted

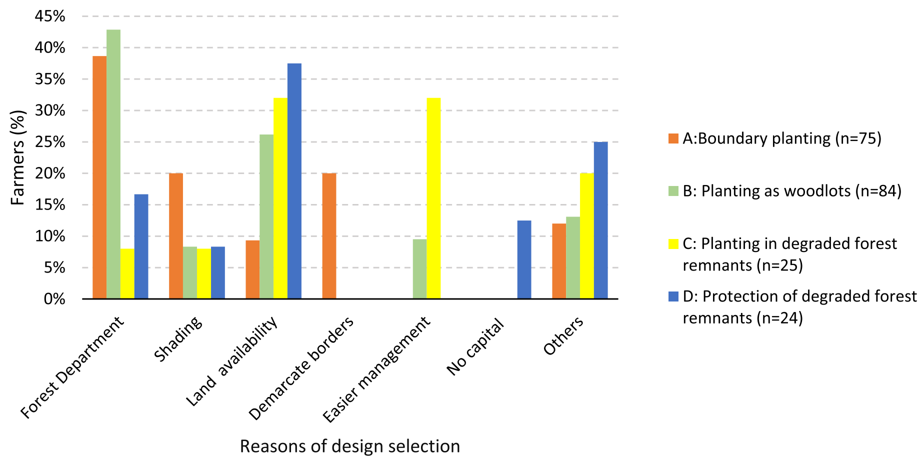

Fig. 4 Farmers' reasons for the selection of different designs in Agroforestry Community Forests (ACF)

trees with degraded forest remnants for easier management. An interviewee said that "I found that the forested areas near my farms have Pyinkado trees (Xylia xylocarpa) which is one of valuable timber producing trees, so I decided to plant more teak trees in the area". (Participant 96/ACF member, personal communication, August 8, 2020). Another interviewee explained that "FD forced to plant trees in our farms. So, we chose to plant trees where we do not grow crops". (Participant 208/ACF member, personal communication, August 8, 2020). For category D, 13% of farmers chose the design due to limited availability of labor and funds for planting new trees.

Finally, although the FD's directive was to reforest agricultural areas, 21% of participating farmers planted trees or maintained natural forest remnants outside the cropping area, specifically in categories C and D.

3.4 Difficulties during the implementation of ACFs

The majority of farmers (55%) did not face any difficulties implementing ACFs, while 34% and 11% of farmers reported to had few and major difficulties, respectively. This was the case for all design categories. The number of farmers who faced a few manageable difficulties is the highest in category B (38%), while 25% of farmers who adopted category D faced more major difficulties than those who adopted the other categories (Fig. 5).

Farmers most frequently mentioned external disturbance factors (44%) such as fire, animals, insects, humans, and land grabbing as difficulties, while 31% mentioned asset-related factors such as capital, labor, soil, and land availability as difficulties (Fig. 6). Seedling-related difficulties, such as insufficient seedlings for planting and patching, seedling transport, and late seedling supply, were also considered difficulties but were less frequently mentioned (8%). Other less-mentioned difficulties were low survival of trees (9%), interference of

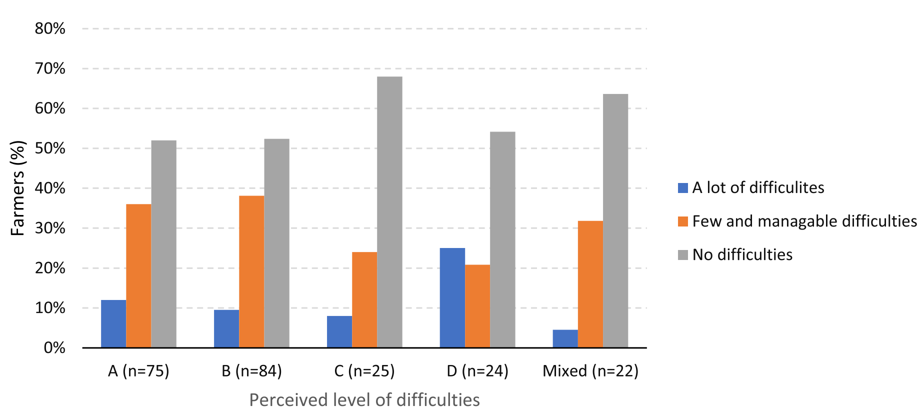

Fig. 5 Percentage of farmers ($n = 230$) with the perceived level of difficulties in different design categories

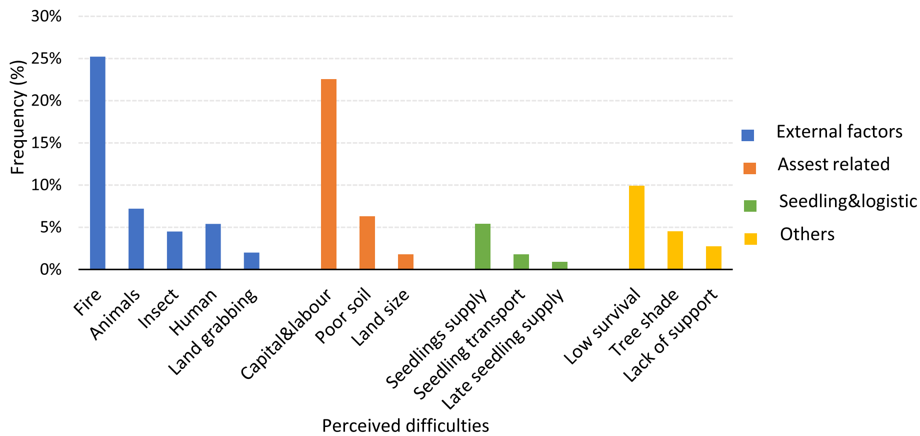

Fig. 6 Frequency of difficulties mentioned by farmers ($n = 103$) during the implementation of Agroforestry Community Forests

trees with crops (5%), and the need for technical support from FD (3%).

In all design categories, interviewed households faced difficulties related to tree destruction by fire and animals such as cows and buffaloes. Fire disturbance was mentioned as the main challenge for the growth of trees in categories A and C, while limited availability of family labor was the main constraint for the maintenance and establishment of ACFs in category B. In category D, the illegal cutting of forest remnants was the major challenge for the farmers.

3.5 Influence of FD in the design selection process

FD provided information to farmers about three planting designs, namely, boundary planting, woodlot planting, and alley cropping. However, only a few households ($n = 25$, 9% of total households) were informed about alley cropping, and none of the farmers adopted this design on their farms. Therefore, alley cropping was omitted as a practiced category.

Twenty-four percent of the interviewees were not informed by the FD about any planting design. A total of 60% were informed of only one planting design, 13% of interviewees received information about two designs, and 3% of interviewees received information about three designs. Thus, only this last group received the complete information for design selection.

Households that were not informed about planting designs were unlikely to participate in tree planting. Only 17% of such households planted trees as ACFs (Fig. 7a). The majority (64%) of them did not adopt ACF and did not plant any trees, while the remaining 19% also did not plant any new trees; however, they claimed that they protected their degraded forests as ACFs instead (category D).

Households that were informed of only one planting design were likely to implement this specific design. Seventy-eight percent of households that were informed about boundary planting implemented this design (category A) (Fig. 7b). Similarly, 63% of households who were informed about woodlot planting implemented this design (category B) (Fig. 7c).

Households that were informed about "category A: boundary planting" and "category B: planting as woodlots" tended to choose category B (Fig. 7d).

We found a significant correlation between the information provided by the local FD and the designs implemented by the households as indicated by a Pearson chi-square test of association ($\chi2$ $(28) = 300$; $p < 0.01$). Therefore, farmers were significantly more likely to practice a design that had been provided by the FD.

3.6 Influence of household characteristics on design selection

The one-way ANOVA showed that the total annual income of the households, household size, number of family laborers, and education of household heads did not differ significantly between the different design categories (Table 2). Only "age of household head" and "total land size" differed significantly between categories, and a pairwise comparison indicated that farmers practicing category D are significantly younger than those practicing design categories A and B. The total land size of farmers implementing category A was significantly smaller than that of farmers implementing category C.

3.7 Evaluation of different design categories

A total of 25% of participating households reported that all trees planted as part of the ACF had been lost by the time of the study. For the farms with surviving ACF trees,

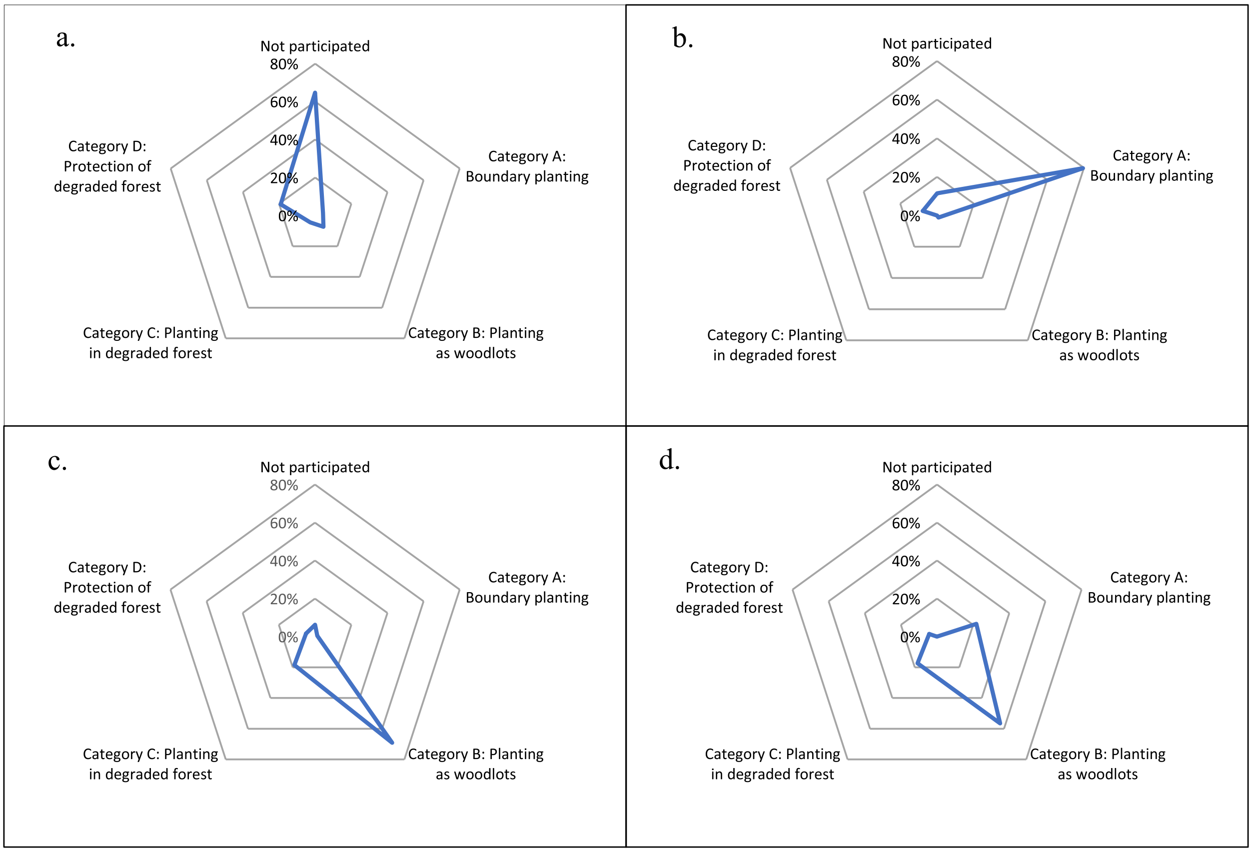

Fig. 7 Percentage of households practicing different ACF planting design categories with **a** Households receiving no information on planting designs ($n=68$). **b** Households who received information about planting trees within farm boundaries ($n=78$). **c** Households who received information about planting as woodlots ($n=81$), and **d** households who received information about boundary and woodlot planting ($n=23$)

we evaluated the stand characteristics of different ACF designs and those in the forest inventory results (Table 3). ACFs with the category A design had on average the lowest density of trees, with 129 ± 75 trees/ha and a mean basal area of 2.53 m^2/ha comparing to other categories.

To compare the inventory results with the FD's goal of planting a minimum of 375 trees per ha of farmland, the average number of trees per ha of the total farmland for all categories was lower than 375 trees for all design categories. In calculating the average trees per ha of total farmland for categories C and D, we also considered the degraded forest remnants as part of the farmer's property based on their perception. The highest average number of trees was therefore 282 trees per ha of farmland in Category C (Table 3) through keeping forest remnant.

Categories C and D had larger basal areas than categories A and B, which was mainly due to the previously existing vegetation and trees within categories C and D. Category B had an overall smaller basal area, although it had more trees per ha than category D. This was because plantations in category B were relatively younger (3–6 years), thus most of the trees had a small DBH.

Overall, category A performed the poorest among the implemented designs, as it had the lowest number of trees and the smallest tree basal areas. According to interviews, category A trees that were planted at farm boundaries were more vulnerable to disturbance by animals, humans, and fire, compared to trees in the other categories. Furthermore, if the planted tree species provided no economic benefit to the farmer, then the farmer tended to provide less care and protection to the trees. During field visits, surviving trees in category A tended to be mainly found between the cropping area and non-arable areas (e.g., stony hills, fallow areas, or streams).

4 Discussion

The results of this study highlight the level of participation of households in ACF, the agroforestry designs implemented, and the condition of trees in ACFs differed from the initial FD recommendations and expectations.

Table 2 Household characteristics of different designs and ANOVA results

	Unit	A: Boundary planting	B: Planting trees as woodlots	C: Planting trees in degraded forest remnants	D: Protection of degraded forests remnants	*P* value (ANOVA)
Mean annual income per household	USD	2468	2120	3243	2133	0.111
Household size	Persons	4.8	4.6	5.2	4.7	0.507
No. family labor	Persons	2.9	3	3.2	2.8	0.673
Education of household head	Level	1.1	1.1	1.2	1.0	0.425
Total land size	Ha	3.9^{a}	$4.6^{a,b}$	6.2^{b}	$4.6^{a,b}$	0.046*
Age of household head	Years	51^{a}	54^{a}	$48^{a,b}$	43^{b}	0.001**

* $p \leq 0.05$, significant ** $p \leq 0.01$, strongly significant. ^{a,b,c} Within a row, values not sharing a common superscript differ significantly ($p < 0.05$)

Table 3 Stand characteristics comparison among different designs

Category	*Plot number*	*Average species number*	*Mean number of trees in forested areas (trees/ha) ± MOE*	*Average forest plot-to-farm ratio*	*Mean number of trees per farm (trees/ha)*	*FD's expectation (trees/ha)*	*Mean basal area (m^2/ha) ± MOE*
A: Boundary planting	12	2	129 ± 75	Around the farm	129	375	2.53 ± 1.6
B: Planting trees as woodlots	15	4	767 ± 282	0.24	184	375	3.98 ± 1.6
C: Planting trees in degraded forest remnants	9	10	1175 ± 464	0.24	282[a]	375	9.31 ± 5.1
D: Protection of degraded forest remnants	6	6	438 ± 180	0.31	136[a]	375	7.79 ± 7.2

MOE Margin of errors, *FD* Forest department

[a] Considering the degraded forest remnants as farmers' farmland

The results show overall poor participation of farmers in ACFs, which has been a major challenge in the success of community forestry projects (Okumu and Muchapondwa 2020; Pagdee et al. 2006). Twenty-one percent of all households in the study did not actively participate in reforesting the agricultural encroachment areas, although they were listed as ACF members by the FD. The major variables affecting participation were the total land size of households and information provided by the FD about ACF. The other household characteristics of farmers, such as age, education, labor, and income did not affect ACF participation. The majority of households reporting a lack of information about ACF as a major reason for not participating also tended to have insufficient land and were generally reluctant to grow trees on their farms. These results agree with those of previous studies conducted in South East Asia and Africa, where the unfavorable attitude of farmers toward tree planting and lack of knowledge of tree planting were the major factors influencing the decisions of households to plant trees or adopt agroforestry practices (Meijer et al. 2015; Le et al. 2021).

The FD is the main source for information transfer related to ACFs, including the different possible designs. However, we found that the FD provided insufficient and inconsistent information on ACF to the farmers. Farmers were likely not to participate in tree planting if they had limited knowledge about ACF designs and practices. Results from similar studies also highlight that a lack of awareness and poor knowledge can hinder the adoption of agroforestry by farmers (Pathania et al. 2020; Bettles et al. 2021). We also found that if farmers were given only one option of planting design, they tended to implement this specific design regardless of their perception. To ensure their long-term participation, consideration of farmers' preferences on designs and provision of sufficient information about different design options are essential to the success of large-scale ACF programs. This recommendation is in line with the findings of other studies that have pointed out the importance of information transfer, access to information, and the effects of information asymmetry in the implementation of agroforestry practices (Bettles et al. 2021; Ullah et al. 2022). Hence, improving information transfer and increasing the level of consideration and inclusion of farmers' perceptions on ACF design selection are necessary steps to ensure the success of future ACF programs.

In addition to providing information on ACFs and their planting designs, the FD also decides which species to distribute, which is done without considering the farmers' preferences. Previous studies have pointed out the importance of participation in the tree species selection process in the adoption and long-term maintenance of agroforestry practices (He et al. 2015; Kasolo and Temu 2008; Leakey et al. 2003; Weber et al. 2001). Including farmers' interests and preferences for the selection of tree species such as multipurpose tree species would increase the motivation to grow trees on farms. Alternative income-generating activities apart from agriculture may help to incentivize farmers to protect and use trees, resulting in a shift from short-term financial interest to the long-term benefits of managing trees (Poscher and San 2022). In addition, given the poor education level of farmers, capacity-building programs for farmers are necessary to enable them to develop an ACF management plan that includes provisions for the selection of their preferred species and designs for ACFs. Previous studies on CF implementation in Myanmar have also highlighted the need for capacity building and technical support for farmers (Tint et al. 2011; Yamauchi and Inoue 2012; Poscher 2017).

A previous study by Soe and Yeo-Chang (2019) identified land tenure insecurity as an important factor affecting participation in forest conservation. In our study, land use rights or land tenure security were mentioned by only a few (3%) farmers as a motivation for adopting ACF, although one of the major benefits of establishing ACFs is secure land use rights according to the Community Forestry Instructions of 1995 and 2018. As farmers have settled on the state forest land for multiple generations, it is possible that farmers already have an informal sense of land use security concerning state land on which farm settlements have encroached. Further investigation in this informal sense of land use security of the encroaching farmers is recommended.

According to our results, the majority of farmers (56%) were pressured by the FD to grow trees, while 44% were motivated by the benefits of ACFs. Other studies have shown that the motivation and interest of farmers were fundamental factors in agroforestry and CFs establishment (Baynes et al. 2015; Gebreegziabher et al. 2021). Therefore, future implementation of ACFs should be based on farmers' motivation and willingness rather than on pressure from the FD.

We found a strong negative perception among farmers regarding growing trees near crops. This perception hindered active participation in ACFs if it involved planting trees near the crops. Even though the FD expects farmers to practice alley cropping as one of the design practices in agricultural encroachment areas, the practice was not widely informed and the ones who were informed did not adopt it because they did not want the trees to disturb crop production in the middle of their fields. Our analysis of tree conditions under the different designs shows that trees in the "boundary planting" design had poor long-term survival, as farmers were worried about crop disturbance from the growing trees, resulting in a low number of trees per hectare. Only the practices that completely separated trees from the cropping areas had higher rates of tree survival. Whenever farmers assumed that planting trees meant sacrificing part of their agricultural income, they tended to lose their motivation to maintain trees on their farms. A study in Indonesia and Bangladesh pointed out that farmers' resistance to changing their agricultural practices to tree-based agroforestry is likely related to the farmers' inability to cope with the expected short-term loss in income from crop production before reaping the economic benefits of trees (Rahman et al. 2016). Further research into the underlying reasons behind farmers' reluctance to grow trees on their farms and ways to change this attitude is necessary. If the FD, non-government organizations (NGOs), and other bodies supporting reforestation through agroforestry intend to maintain long-term farmer participation, it is important to create an inherent interest in farmers in growing trees by first educating them about the benefits of agroforestry and the interactions between trees and crops in agroforestry systems.

To help farmers understand the benefits of ACFs, we recommend establishing farmer field schools that can show successful cases of agroforestry practices and ACFs in a similar agroecological zone. Farmers-to-farmers training and knowledge sharing have proven to be successful for the adoption of sustainable land use practices including agroforestry (Böhringer 2001; Kansanga et al. 2021). Furthermore, many studies in Myanmar and other countries have shown the potential benefit of agroforestry in comparison to conventional agriculture, with the former generating more environmental stability and economic profits (Córdova et al. 2018; Thinn et al. 2020; Duffy et al. 2021). Hence, to ensure the long-term participation of farmers, they should have a full understanding of the benefits of ACFs and such knowledge should be transferred through well-established extension services or capacity-building training. Securing more resources, especially adequate staffing and financial support is also needed for both farmers and the FD (Tint et al. 2011).

Participating farmers also reported that external disturbances caused by fire, livestock, and humans, as well as financial and labor constraints, were the main difficulties during ACF implementation and management. Providing technical and financial support for farmers by the government or other agencies such as NGOs as well as building a platform or network to provide support for farmers can be a useful tool to handle the difficulties faced during ACF establishment. Establishing revolving funds among members may also be a way to overcome the problem of limited financial resources (Khaing et al. 2019).

Degraded natural forest-based designs performed well as ACFs, and all farmers who implemented these categories successfully maintained forested land at the time of the study. Clearing degraded forests or natural forest remnants to grow monocultural plantations has been criticized as “agrodeforestry” (Ollinaho and Kröger 2021) and should be avoided. Hence, whenever non-arable or unused land is available, farmers should be encouraged to plant additional indigenous trees in the degraded natural forest remnants, rather than clearing the natural vegetation to establish tree plantations. In this way, the existing conditions of forest remnants in or around the farms can be improved as well as protected from further encroachment while providing benefits of the ACFs to the farmers. The success of this approach was reported in Nepal, where CF was implemented by forest encroachers to conserve state forest remnants (Bhusal et al. 2018).

We found that the goal of the FD to transform the agricultural encroachment areas into agroforestry farms was not achieved in the study area. Although the applied CFs framework was originally developed as a bottom-up approach, the FD adopted a top-down approach in implementing ACFs. Many studies have pointed out the inefficiency of a top-down approach and the necessity for continuous governmental support of agroforestry-based reforestation programs, especially in the global south (Höhl et al. 2020; Bettles et al. 2021). To ensure the long-term participation of local farmers in community-based farmland reforestation activities and to increase the effectiveness of such activities, it is necessary to increase farmers’ awareness of agroforestry systems and their benefits. Farmer acceptance of planting trees can be enhanced by considering their preferences, providing capacity-building training, developing incentives for long-term participation, and providing continuous technical support throughout the transition from agriculture to agroforestry. In addition, improved coordination and communication between the relevant ministries overseeing farmers, especially the ministries of agriculture and forestry, is recommended. These ministries should work to support clear tenure rights, enforce the law, and hamper illegal activities to prevent future agricultural expansion in forests.

Furthermore, the political situation under military rule in Myanmar is currently unstable and unfavorable for sustainable forest management (MONREC 2021). A stable and democratic political situation, a re-established rule of law with reduced corruption, openness to international financial and technical support, and well-functioned and coordinated government institutions are also important frame conditions that could support the long-term success of the ACF program.

5 Conclusions

The level of participation of households in ACF implementation was much lower than what the FD expected and claimed. The reasons for non-participation were related to insufficient land size, limited knowledge about ACFs, and the general reluctance of farmers to grow trees close to their crops. The majority of farmers adopted ACFs due to pressure from the FD, rather than inherent motivation. Participating farmers implemented four different ACF design categories, and FD greatly influenced farmers’ decisions on design and species selection. However, because of the negative perception on growing trees near crops, farmers tended to plant trees in degraded forest remnants or outside the cropping areas.

To improve this situation, we suggest that the FD should consider farmers’ perceptions and interest in ACF implementation, especially during the species and design selection process. A strategy to provide sufficient funds and qualified human resources that will invest time and effort in ACF establishment, as well as to provide incentives that will motivate farmer participation should be developed by the FD or the implementing agencies. In addition, farmer field schools and well-functioned extension services should be established to increase farmers’ interest in the socioeconomic and ecological benefits of agroforestry practices. A stable political situation, close coordination between ministries, reduced corruption, and better rule enforcement would be beneficial to increase the chances of successful ACF adoption and increased sustainability.

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Authors’ contributions

Su Mon San: conceptualization, methodology development, data collection and analysis, interpretation of results, writing—original draft preparation, reviewing and editing. Navneet Kumar: reviewing and editing, validating, and approving. Lisa Biber-Freundenberger: reviewing and editing, validating, and approving. Christine B. Schmitt: support in conceptualization, support interpretation, supervision, reviewing and editing, validating, and approving. All of the authors read and approved the final manuscript.

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Availability of data and materials
The data that support the findings of this study will be made publicly available in Zenodo repository (https://zenodo.org/record/7950742) only after submission of the main author's PhD thesis. Data are however available from the authors upon reasonable request.

Declarations

Ethics approval and consent to participate
The authors declare that they obtained the approval of ZEF Research Ethics Committee from Center of Development Research, University of Bonn, for conducting the present study based on Interviews/survey.

Consent for publication
All authors gave their informed consent to this publication and its content.

Competing interests
The authors declare no conflict of interest.

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