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Determinant of farmers' participation and biodiversity status in the program of agroforestry rehabilitation in Sudan

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Abstract. *Hemida M, Mulyana B, Vityi A. 2022. Determinant of farmers' participation and biodiversity status in the program of agroforestry rehabilitation in Sudan. Biodiversitas 23: 5638-5645.* The agroforestry Rehabilitation Program (ARP) was launched in Nabag Reserve Forest (NRF), Sudan, to rehabilitate the forest cover and improve livelihoods for communities around the forest. To enhance the efficacy of such rehabilitation programs, it is crucial to understand the impact of various factors on community perception of participation in forest rehabilitation. The objectives of this study were to (i) examine the factors that influence farmers' perceptions of their involvement in the program and (ii) assess the biodiversity of trees and crop species in the program. Data was gathered through a survey that included personal interviews with 200 farmers who participated in the program. A total of 250 circular sample plots were established randomly to achieve the second objective. The results showed that extension services, farming experience, family members, educational level, land size, and gum Arabic production positively influence farmers' perceptions. The study findings identified nine tree species and five crop species in NRF. The dominant tree species were *Acacia senegal* and *Balanites aegyptiaca* which represented 62.8% and 12.4 % of the total species, respectively. At the same time, groundnut and watermelon were identified as favorite crops cultivated by farmers. Furthermore, the non-rehabilitated area has shown better value in richness, heterogeneity, and evenness than the rehabilitated areas.

Keywords: Diversity, farmers' participation, local communities, Nabag reserve forest, *Taungya* system

INTRODUCTION

Sudan has a land area of 1.9 million km^2 with 29.8 million hectares of forest cover (FAO 2020). The forest resources of Sudan play a crucial role in sustaining human life. Most people in Sudan rely on wood and non-wood forest products as their primary source of income and daily food consumption, especially in rural areas (Fahmi et al. 2018). This has resulted in deforestation and land degradation (Badri 2012). Another cause of land degradation in Sudan is the clearance of rangeland for mechanized rain-fed agriculture and shifting cultivation (Biro et al. 2013). This has a substantial negative impact on soil fertility and biodiversity conservation (Ardiyaningrum et al. 2021). To address these issues, however, rehabilitation initiatives in Sudan have been implemented, with a promising trend in increasing vegetation cover and conserving biodiversity (Mohammed et al. 2016). In Sudan, however, many initiatives have been made to rehabilitate degraded forests to reverse deforestation and forest degradation trends. In this regard, the *Taungya* agroforestry system is considered one of the strategies implemented by the Forest National Cooperation (FNC) in Sudan to halt deforestation and forest degradation and as a livelihood improvement for the communities surrounding the forest reserves. In this program, the FNC targets specific degraded areas inside the forest to be planted by farmers with specific tree species and crops. (El Tahir et al. 2015). According to Rahman et al. (2017), any restoration efforts for biodiversity are subject to the livelihood development of communities that live around the forest. Thus, rehabilitating forest-dependent people is a promising technique for biodiversity conservation (Shylendra 2002). However, although forest rehabilitation initiatives such as the *Taungya* agroforestry program in Sudan are crucial habitats for flora (e.g., such as *Acacia senegal, Acacia seyal,* and *Balanites aegyptiaca*) and fauna (e.g., *Canis mesomelas*, *Panthera pardus*, and *Ammotragus tragelaphus* (Hasoba et al. 2020; Siddig et al. 2018). The lack of awareness about the value of biodiversity, as well as insufficient structures for integrated biodiversity management, has exacerbated already deteriorated biodiversity in Sudan (Yasin and Mulyana 2022). Moreover, other issues, such as climate change and habitat fragmentation, have a potential impact on forest diversity (John et al. 2020) Therefore, providing current status data on biodiversity, such as species composition, richness, heterogeneity, and evenness is crucial for planning and implementation of biodiversity restoration (Eisawi et al. 2021) and creating an effective sustainable forest management plan (Baillie et al. 2008).

Farmers' perceptions of agricultural technologies such as agroforestry practices are influenced by various factors, including socioeconomic and institutional factors (Gebru et al. 2019). The socioeconomic factors are age, gender, education level, land size, and family members (Tey and

Brindal 2012). Institutional factors include agricultural associations, access to credits, and extension services (Mwaura et al. 2021). Maswadi et al. (2018) found that land size, family size, age, and education positively affect farmers' perceptions. Likewise, education level, land size, access to training, and extension services were found to positively and significantly influence farmers' perceptions of the benefits of practicing agricultural technologies (Moges and Taye 2017). Thus, a better understanding of these factors is critical for providing valuable information to technology providers and essential for the success of the policy and program (Thompson et al. 2019; Oo and Usami 2020). This will undoubtedly contribute to the improvement of farming practices for conservation and sustainability (Zafeiriou et al. 2021). Particularly in Sudan, the number of studies exploring the factors that affect farmers' perceptions of forest rehabilitation programs is relatively small and limited. Therefore, this study will build on the existing literature by analyzing these factors. Understanding these factors could facilitate the implementation of other rehabilitation schemes in the future. Therefore, the objectives of this study were to (i) examine the factors influencing farmers' perceptions of participation in the ARP and (ii) assess the biodiversity of trees and crop species in the ARP.

MATERIALS AND METHODS

Study area

This study was carried out in South Kordofan State, Sudan. Nabag reserve forest (NRF) has been taken as a case study. It lies between the latitude 12° 30' 0" N and 12° 36' 0" N and the longitude 29° 52' 0" E to 29° 58' 0" E (Figure 1). Since 1961, 4174.2 hectares of NRF have been declared as the state forest and managed by Forest National Corporation in South Kordofan State (Abdel Magid and Mohamed 2015). Furthermore, Abdel Magid and Mohamed (2015) described that the vegetation species in these areas were *Acacia senegal*, *Azadirachta indica*, *Balanites aegyptiaca*, and *Sclerocarya birrea*. The annual rainfall of the study area is between 350 - 850 mm, while the average temperature ranges from 20 - 35 °C (Adam and Bello, 2017). Presently, at least nine villages surround the forest and rely on agriculture mainly, cropping and livestock rearing, and natural forest products as the main sources of their livelihood. It is worth mentioning that agricultural crop production is practiced inside the forest land area.

Data collection

Data was collected in the summer of 2021, targeting 200 farmers from nine villages around the forest. Both primary and secondary means were used. Primary data was collected using semi-structured questionnaires, focus group discussions, key informant interviews, and direct field observations. To ensure validity and reliability, the questionnaires were pre-tested with ten respondents. As part of ethical issues, before starting the interview session, the researcher explained the purpose of the research to the respondents, and verbal consent was obtained from them to participate in the interview. The interviews ranged from 20 to 45 minutes and were mostly held in the village leader (Sheikh) or places where the respondent was available. The secondary data was gathered from various documents, archival records, reports by FNC, available literature (articles, books, policy briefs), and internet sources.

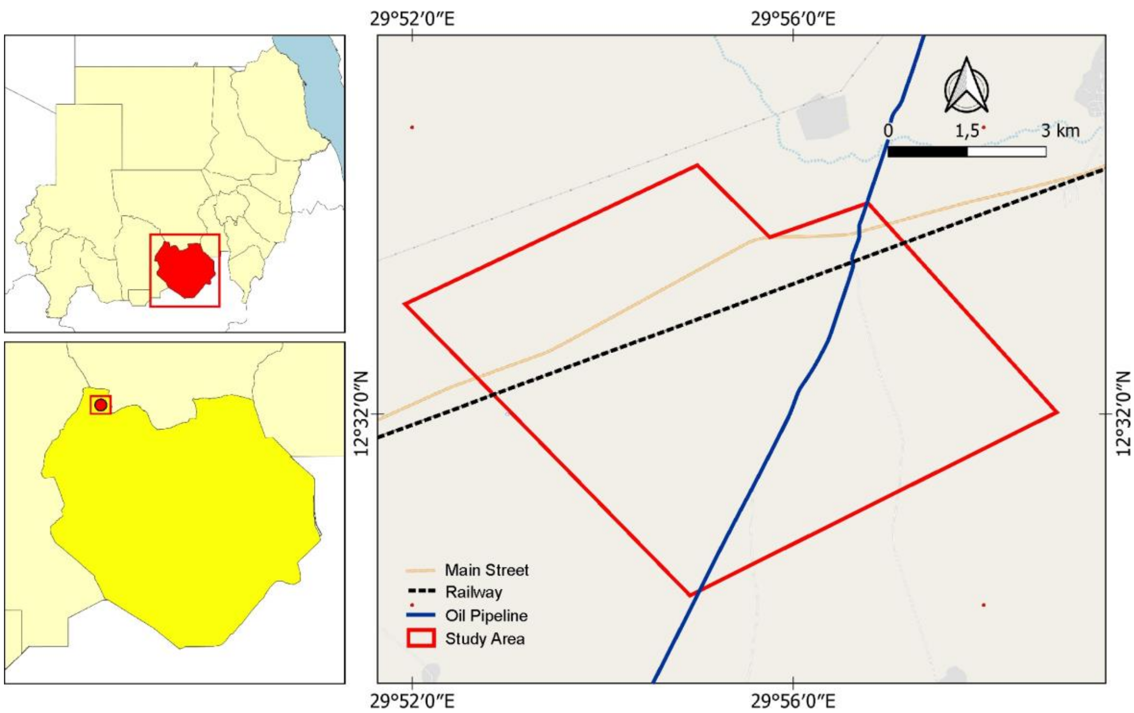

Figure 1. Map of the study area in Nabag reserve forest (NRF), South Kordofan State, Sudan

Table 1. A general description of the variables used in the study, Nabag reserve forest (NRF), South Kordofan State, Sudan

Variables name	Code	Type	Unit of measurement
Gender of the farmer	GEN	Dummy	1= male; 0=female
Age of the farmers	AG	Continuous	Measured in years
Education level	EDU	Continuous	Illiterate =1; *Khalwa** =2; Primary =3; Secondary =4; University =5
Family size	FSIZ	Continuous	Measured in number
Land size	LSIZ	Continuous	Measured in *Mukhamas***
Taungya experience	TAUNEXP	Continuous	Measured in years
Extension services	EXTEN	Dummy	If the farmer gets extension services=1; otherwise=0
Gum Arabic	GUM	Dummy	If the farmer participates in gum Arabic production=1; otherwise=0

Note: *A religious school in which Muslims learn the Holy Qoran and Qoran studies. ** Land unit in the study area (1 *Mukhamas*= 0.75 hectare)

Biodiversity data was collected by establishing a total of 250 circular sample plots (0.1 ha), which were distributed randomly to cover the study site by using the open-source software QGIS. All samples were entered into the Global Positioning System (GPS) and used for the field survey. To assess the species composition, the name and number of individuals for each species in each sample plot were recorded (Yasin and Mulyana 2022; Mwendwa et al. 2020).

Data analysis

The collected data was analyzed using Statistical Package for Social Sciences (SPSS) software, version 22.0. Simple descriptive analysis was used to compute frequencies, percentages, the mean, and standard deviation for some socioeconomic variables of respondents as well as for tree and crop biodiversity. An ordinal logistic regression model was applied to analyze the effect of different factors on farmers' perceptions. The ordinal logistic regression was chosen because it has been widely used to study the factors that influence farmers' perceptions of different technologies (Mwaura et al. 2021; Li et al. 2022; Abegunde et al. 2019). Furthermore, when the outcome variables are ordinal rather than continuous and have more than two categories, the model is considered a suitable analytical method (Williams 2016). The validity of the model assumptions was checked by testing the two key assumptions; first: the multicollinearity between the independent variables, and second: the parallel line or proportional odds assumptions by following (Chandra et al. 2022; Williams 2006). The Variance Inflation Factor (VIF) was used to test for multicollinearity, with a value of > 10 indicating severe collinearity, whereas for the parallel line assumption, the model should not be violated to ensure that the estimated effects are the same across all categories by setting the p-value to not significant (Chandra et al. 2022). The dependent variable used in the model was farmers' perception, while the independent variables were family size, education level, age, gender, land size, years of participation in the *Taungya* program, participation in gum Arabic production, and access to extension services. The variables were selected based on the field survey result and literature review (Ntshangase et al. 2018; Beshir et al. 2022; Majbar et al. 2021). Table 1 provides a summary of the selected variables.

Biodiversity data were analyzed using the common standard protocol for biodiversity assessment widely used by scholars (Jannat et al. 2020; Dafa-Alla et al. 2022; Neelo et al. 2013; Nugroho et al. 2022). Three diversity indices were analyzed, namely species Richness (R), Heterogeneity (H), and Evenness (E) respectively, to get a picture of tree species diversity in the study area.

RESULTS AND DISCUSSION

Characteristics of the farmers in the study area

The major socioeconomic traits of the farmers are represented in Table 2. The majority of the farmers (77%) were male, and the others were female, with ages ranging from 18 to 90 years. Most farmers (57.5%) were 36-55 years (Table 2). This suggests that although most of the farmers were above a young age, they were still considered within an economically active age range, meaning they could participate effectively in agricultural activities. Out of the total of farmers (79%) had attained both formal and informal education ranging from *khalwa* to university, while only 21% were illiterate (Table 2). This means they are more likely to understand the related extension programs and have access to up-to-date agricultural technologies than illiterate farmers. The mean family size was found to be five people (Table 2).

Regarding the land size, the study found that the mean land area cultivated by farmers was five *mukhamas*. About 77% of farmers have cultivated land sizes ranging from 1 to 5 *mukhamas*. However, the limitation of the land area could be explained by the nature of the agroforestry rehabilitation program as targeting specific land areas inside the forest reserve. The average number of years of participation in the *Taungya* program was 6.70 years. Most of the farmers, 57.5%, had *Taungya* experience ranging between 1-5 years, while the others, 23%, 15.5%, and 4%, had experience of between 6-10 years, 11-15 years, and more than 15 years, respectively (Table 2). This implies that the farmers wll accept *Taungya* agroforestry practice and the number of adopters is increasing. At the same time, farmers in the study area have enough experience in practicing *Taungya* agroforestry. It suggests that they are aware of different silvicultural operations and technologies. Thus, they will likely continue participating in the *Taungya* agroforestry program. The assertion was supported by Adeoye et al. (2015), who noted a positive correlation between years of experience and household participation in the *Taungya* system in Oluwa Forest Reserve in Nigeria.

Factors influencing farmers′perception of participation in Agroforestry rehabilitation program

The logistic regression analysis results in Table 3 found that out of eight explanatory variables included in the model, six variables were found to positively influence farmers' perceptions of participation in the forest rehabilitation program. These include extension services, family members, educational level, land size, *Taungya* experience, and gum Arabic production (Table 3). In contrast, the gender (β = -0.43, P = 0.182) and age of the farmers (β = -0.028, P = 0.03) had a negative association with farmers' perception (Table 3).

The extension service was a crucial factor and had a positive and significant effect on farmers' perception with the odd ratio of (2.162, P >0.05). This means that access to extension services could lead to raising farmers' perception by a factor of 2.162 (Table 3). This could be explained by the fact that extension services provide farmers with information such as farming technologies that could increase farm productivity and boost farmers' skills and awareness, raising their perception. This result is in line with other studies by Tatlidil et al. (2009); Kabir and Rainis (2012) reported an increase in farmers' perception of the increasing extension services and contacts.

Table 2. General characteristics of the farmers in the study area, Nabag reserve forest (NRF), South Kordofan State, Sudan

Variables	Category	Frequency (%)	Mean (SD)
Gender	Male	154 (77)	
	Female	46 (23)	
Age	18-25	20 (10)	40.96 (12.36)
	26-35	45 (22.5)	
	36-55	115 (57.5)	
	>55	20 (10)	
Educational level	Illiterate	42 (21)	
	Khalwa	46 (23)	
	Primary	69 (34.5)	
	Secondary	33 (16.5)	
	University	10 (5)	
Family size	1-5	97 (48.5)	5.97 (3.43)
	6-10	84 (42)	
	11-15	16 (8)	
	>15	3 (1.5)	
Land size	1-5	154 (77)	4.66 (3.77)
	6-10	29 (14.5)	
	11-15	14 (17)	
	>15	3 (1.5)	
Taungya experience	1-5	115 (57.5)	6.70 (3.50)
	6-10	46 (23)	
	11-15	31 (15.5)	
	>15	8 (4)	

Table 3. Factors influencing farmer's perception of participation in Agroforestry rehabilitation program

Variables	Coef. (β)	Std. Error	P-Values	Exp (β)
Extension services	0.771	0.31	0.013*	2.162
Gender	-0.43	0.322	0.182	0.651
Family members	0.043	0.045	0.345	1.044
Age	-0.028	0.013	0.03*	0.978
Educational level	0.065	0.119	0.583	1.067
Land size	0.056	0.035	0.11	1.058
Taungya experience	0.126	0.04	0.002*	1.134
Gum Arabic production	0.032	0.322	0.92	1.033

Note: *Indicates a significant difference at $p < 0.05$

Similarly, the study findings in Table 3 revealed that the *Taungya* experience had a significant positive effect on farmers' perception with an odd ratio of 1.134 (P >0.05). This suggested that the probability of increasing farmers' perception of the benefits of *Taungya* agroforestry increased by 1.134 times with an increase in years of participation in the *Taungya* program. A reasonable explanation for this result could be that farmers with enough *Taungya* experience are more likely to get and use the information relevant to silvicultural operations and production, which may increase their perception of the *Taungya* benefits. The family members variable was found to positively affect farmers' perception of the benefit of *Taungya* agroforestry. The results indicated that as family size increases, the likelihood of farmers' perception increases by a factor of 1.044 (Table 3). This could be a reasonable outcome because, in most cases, having more family members means having more labor available to diversify household income. The positive association between family members and the likelihood of raising perception toward agroforestry adoption can be found in other studies (Basamba et al. 2016; Nyamweya and Moronge 2019).

The educational level attained by farmers showed a positive influence on farmers' perception in the study area. The result shows an increase in the educational level attained by farmers would increase their perception by a factor of 1.067 (Table 3). This is not a surprising result since farmers with some formal or informal education are more likely to understand the consequent benefits of agroforestry practice as they are easily able to digest new knowledge and are more able to change their perception in comparison to illiterate farmers. The survey results show that farmers in the study area had limited farmland. Land size cultivated by farmers was found to positively affect farmers' perceptions. The odd ratio results in Table 3 revealed that an increase in land size by one unit would increase the farmer's perception by a factor of 1.058. Previous studies on agroforestry practices observed a similar positive association between farm size and farmers' perception (Admasu and Jenberu 2022; Mahmood et al. 2020). The finding, however, is inconsistent with the studies of Akinwalere (2016) in Nigeria and Mwaura et al. (2021) in Kenya, who observed a negative correlation between total land cultivated and farmers' perception of the benefit of using new agricultural technologies. The effect of participation in gum Arabic production on farmers' perception is like the land size. The participation of farmers in gum Arabic production probably increases their perception of the benefits of *Taungya* agroforestry by a factor of 1.033 (Table 3). This is perhaps because participation in gum Arabic production provides farmers with an additional source of income that motivates them and raises their perception of the benefits of *Taungya* agroforestry. It implies that farmers participating in gum Arabic production were more aware of the benefits of *Taungya* agroforestry.

The predicted age variable coefficient was found to negatively affect farmers' perception of the benefits of *Taungya* agroforestry. Showing that as the age of the farmers increases by one year, their perception would decreases by a factor of 0.978 (Table 3). This means that older farmers may be less interested in or reluctant to participate in the *Taungya* agroforestry compared to the younger farmers. Moreover, the reality in the study area showed that most farmers lie within an economically active age range that raises their knowledge and perception. This is supported by the findings of Sharmin and Rabbi (2021) in Bangladesh, who reported that younger farmers are more knowledgeable about the benefits of Agroforestry than old farmers.

Similarly, the results from regression analysis in Table 3 also show that the sex of farmers negatively influenced farmers' perceptions. This result indicates that a change in the gender of the farmers could decrease the perception by a factor of 0.651(Table 3). Since the male farmers formed the majority of respondents in the study area (Table 2), it implies that they perceived *Taungya* agroforestry as beneficial compared to female farmers. Studies support this claim by Catacutan and Naz (2015) and Diawuo et al. (2019), who highlight that women have higher constraints in practicing agroforestry than men due to their lower education level, poor access to extension assistance, and multiple domestic responsibilities. Likewise, Galabuzi et al. (2021) and Jahan et al. (2022) found that male farmers were more positive than females towards Agroforestry practices.

Biodiversity of trees and crops in the agroforestry system in the study area

The research site was rehabilitated during the period 2004-2012 by planting the gum Arabic tree (*Acacia senegal*). Gum Arabic tree with agroforestry practice has been chosen by the management of Forest National Cooperation and community to ensure successful rehabilitation program and increase the livelihood income. The consequence of this choice was less biodiversity (Table 4). The component of species diversity, richness and evenness in human-made ecosystems have not shown a consistent pattern (Ma and Eriksson 2005). The research findings have demonstrated irregular patterns among the rehabilitation sites. The lowest value on biodiversity indices occurred in the compartment of rehabilitation in the year 2005 (Table 4). Based on observation, the rehabilitation program has been started from the bare land. Although the highest value occurred in the non-rehabilitated areas, this area is still low in tree density and needs enrichment planting to increase the forest cover. Furthermore, the non-rehabilitated areas should get high attention from the FNC and community to maintain their biodiversity.

Table 5. Species diversity of trees and crops in agroforestry system

Tree species composition	Frequency (%)	Crop species composition	Frequency (%)
Bare land	78(31.2)	Single species	
Single species		G	28(14)
AS	125(50.0)	S	13(6.5)
BA	4(1.6)	W	14(7.0)
SB	3(1.2)	H	5(1.5)
AI	1(0.4)	Multispecies	
Multispecies		G_S	47(23.5)
AS_BA	15(6.0)	G_W	2(1.0)
AS_AN	2(0.8)	G_S_C	29(14.5)
AS_FA	2(0.8)	S_C_W	3(1.5)
AS_SB	3(1.2)	G_S_C_W	25(12.5)
AS_AA	3(1.2)	G_S_C_W_H	36(18.0)
AS_AI	1(0.4)		
AS_BS	1(0.4)		
BA_SB	2(0.8)		
BA_AA	2(0.8)		
BA_BS	1(0.4)		
AS_AN_BA	1(0.4)		
AS_BA_AI	1(0.4)		
AS_BA_SB	4(1.6)		
AS_AM_AN_BA_AI_AA_FA_SB_BS	1(0.4)		

Note: AA: *Albizia ammara*, AI: *Azadirachta indica*, AM: *Acacia mellifera*, AN: *Acacia nilotica*, AS: *Acacia senegal*, BA: *Balanites aegyptiaca*, BS: *Boscia senegalensis*, SB: Sclerocarya birrea, FA: *Faidherbia albida*, C: Cowpea, G: groundnut, H: hibiscus, S: sesame, W: watermelon

Table 4. Biodiversity indices in the agroforestry rehabilitation program at Nabag reserve forest (NRF), South Kordofan State, Sudan

Year of rehabilitation	Area (ha)	Number of species	Richness	Heterogeneity	Evenness
2004	21	2	0.48	0.38	0.54
2005	21	1	0.00	0.00	0.00
2006	84	2	0.51	0.41	0.59
2007	546	2	0.38	0.26	0.37
2008	420	3	0.51	0.44	0.40
2009	420	6	1.12	0.85	0.47
2010	420	4	0.56	0.21	0.15
2011	252	7	1.04	0.72	0.37
Non-rehabilitated	1990.2	7	0.98	1.93	0.99

In total, nine tree species and five crop species have been identified in the agroforestry system in the study area (Table 5). *Acacia senegal* was found in the 157 sample plots (62.8%), followed by *B. aegyptiaca* (12.4%) and other species (*Acacia mellifera, Acacia nilotica, A. indica, Albizia ammara, Faidherbia albida, S. birrea,* and *Boscia senegalensis*) were 14.0%. The nature of the rehabilitation program could explain the dominance of *A. senegal* species in the study area, as the national forest corporation was targeting *A. senegal* plantation for gum Arabic production as its primary objective (Mohamedain et al. 2012). Gum Arabic trees (*A. senegal and A. seyal*) are dominant species planted in Sudan as part of a rehabilitation program (Mohammed et al. 2021a; Yasin and Mulyana 2022; Younis et al. 2022). Likewise, the appearance of *B. aegyptiaca* as a second dominant tree species in the study area could be due to its importance as a native tree species that is frequently used by the local people that live around the forest reserves in Sudan as a multipurpose species for food, feed, medicinal purposes, and livelihoods (Mohammed et al. 2022; Fadl 2015). The other plots have no tree species (bare land), one tree species, and multispecies (more than two species). Similar conditions can also be found in the Tozi tropical dry forest in Sinnar State, Sudan (Yasin and Mulyana 2022), Abu Gadaf natural reserved forest, Sudan (Mohammed et al. 2021a), and Dinder biosphere reserve, Sudan (Mohammed et al. 2021b). The main factor affecting the bare land and low tree density in Sudan is erratic and low precipitation (Mohammed et al. 2016). However, crop species (groundnut, sesame, cowpea, watermelon, and hibiscus) were found in single or multiple cultivations at all sample plots.

Agroforestry practices are essential to support the success of forest rehabilitation programs. For instance, the local knowledge of indigenous people in Atok, Benguet, the Philippines, on ecological restoration has been integrated into the tree on their farms (Landicho et al. 2021). A similar pattern is also found in Ethiopia, where indigenous people combine the cops and multipurpose tree species (Lelamo 2021). In this research, indigenous people prefer cultivating groundnut and sesame for the crops and *A. senegal* for the tree. This could be explained by the fact that groundnut and sesame are considered significant cash crops in the study area (Abdalla et al. 2015). According to the focus group discussions, farmers revealed that roughly 80% obtained household incomes from cultivating groundnut and sesame.

In conclusion, this study showed that several interconnected factors impeded farmers' participation in ARP, including extension services, family members, educational level, land size, *Taungya* experience, and gum Arabic production. Therefore, the study recommended that much attention should be given to these factors before implementing any ARP in the future. Moreover, in terms of biodiversity, the study concluded that biodiversity indices in rehabilitated areas are lower than those in non-rehabilitated areas. Thus, in the future, more attention should be given to enriching biodiversity by introducing more multipurpose trees.

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