JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
Volume 13, Number 2 (April 2026):10099-10114, doi:10.15243/jdmlm.2026.132.10099
ISSN: 2339-076X (p); 2502-2458 (e), www.jdmlm.ub.ac.id

Research Article

The uncertainty of the Social Forestry Program in ensuring environmental sustainability in upstream watersheds: a case study of the Sekampung Watershed in Lampung, Indonesia

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Article history:
Received 30 January 2026
Revised 7 March 2026
Accepted 11 March 2026

Keywords:
adoption
coffee
community-forest
conservation
smallholders
soil

Abstract

Building awareness of the importance of proper land management is essential for ensuring the long-term sustainability of upstream watershed areas. This study investigated how land management practices emerge, evolve, and are adopted within the Social Forestry Program in the upstream Sekampung watershed. Exploration was focused on three key aspects: (1) the characteristics of social forestry participants as evidence of ongoing community social transformation; (2) the level of land management across different social, economic, and ecological contexts; and (3) the main factors influencing farmers' decisions to implement sustainable land management practices. A total of 125 respondents were selected to represent program participants. Land management was categorized into biological and mechanical conservation technologies. A logistic regression model was applied to analyze the probability of farmers adopting conservation practices. Results showed that the Social Forestry Program has facilitated considerable social transformation by strengthening community participation and institutional support. It also promoted diverse land management practices adapted to local conditions. Logistic regression analysis identifies several key determinants influencing farmers' decisions to adopt soil conservation: coffee plant age, farmer age, family size, land area, education level, and farming experience. The logistic model provides robust analytical grounding. It provides high-quality empirical evidence, interdisciplinary relevance, and policy-relevant insights, making it a valuable addition to the scientific literature on sustainable land management, community forestry, and smallholder resilience.

To cite this article: Fitriani, Arifin, B., Rosanti, N., Shomura, H., Kazuto, S., Yuwono, S.B., Dermiyati, Rahmalina, D., Lestari, F.Y. and As-Sadili, A.H. 2026. The uncertainty of the Social Forestry Program in ensuring environmental sustainability in upstream watersheds: a case study of the Sekampung Watershed in Lampung, Indonesia. Journal of Degraded and Mining Lands Management 13(2):10099-10114, doi:10.15243/jdmlm.2026.132.10099.

Introduction

Watersheds play a crucial role in supporting life by providing clean water, irrigation, and other important ecosystem services. The upstream watersheds, especially the forest areas, serve as water catchment areas, help prevent erosion and sedimentation, and host significant biodiversity and carbon stocks. Forests globally are the second-largest carbon store after oceans. Forests in tropical regions, including

Indonesia, have a very high potential for carbon storage, both in biomass (vegetation) and in soil. Forest degradation releases carbon dioxide (CO2) into the atmosphere, contributing to climate change. According to the State of Indonesia's Forests (SOIF) 2022 report from the Ministry of Environment and Forestry (KLHK), Indonesia's forests store around 31.7 GtC (Gigatons of Carbon).

Changes in land use in forest and watershed areas cause deforestation, soil damage, erosion, sedimentation, and loss of biodiversity, which results in widespread disruption of ecosystem service functions. Deforestation, unsustainable land conversion, and inappropriate forest management practices can threaten these vital ecological functions, including carbon storage. Land degradation in upstream watersheds due to erosion and sedimentation not only reduces water quality and shortens reservoir lifespans, but can also disrupt the hydrological cycle and reduce the land's ability to store carbon. Loss of forest cover also reduces transpiration, which can affect regional rainfall patterns. The root of deforestation in Indonesia is pressure to expand livelihoods, sources of income, and the economic needs of the community. Research in various watersheds in Indonesia shows a negative correlation between the level of forest cover in the upper reaches and the occurrence of floods and landslides downstream. Soil erosion also causes the loss of fertile soil layers rich in organic carbon (Rahman et al., 2021; Fitria and Kurniawan, 2023).

Therefore, community involvement in the program to restore forest functions is a pillar of Indonesia's social forestry program. Forestry programs in Indonesia are regulated by the government. The program focuses on maintaining the extent of forest areas and protecting upstream areas as water catchment areas. Social Forestry Management includes various schemes, consisting of: Village Forests (hutan desa/HD); Community Forests (hutan kemasyarakatan/HKm); Community Plantation Forests (hutan tanaman rakyat/HTR); Customary Forests (hutan adat/HA); and Forestry Partnership (Government Regulation Number 23 of 2021; Regulation Nu 9/2021 Minister of Environment and Forestry)(http://pskl.menlhk.go.id/).

Social Forestry, as a forest management system that involves local communities as the main actors, has great potential in improving land conservation while providing economic and social benefits. When communities have rights and responsibilities in forest management, they tend to be more motivated to maintain its sustainability. Social forestry in upstream watersheds faces the challenge of complexity, where socio-economic and ecological factors interact dynamically. Integration of biophysical factors (e.g., rainfall, slope, soil type) and oversight of the socio-economic drivers of land-use decisions, such as farmer participation, preferences, economic incentives, and policy frameworks, plays an important role in the success of the policy program. Upstream watersheds are characterized by complex interactions between ecological processes. Current policy program modeling often fails to capture these dynamics, leading to oversimplified and less actionable recommendations (Nugroho et al., 2022; Christian et al., 2024). By involving local stakeholders in the modeling process and evaluating the dynamic interactions between ecological and socio-economic systems, this study will provide a more holistic understanding of soil conservation challenges and opportunities.

Land management practices in the Social Forestry system include reforestation, agroforestry, and sustainable forest management, which directly increase carbon sequestration. Tree planting increases biomass, while good soil management practices can increase soil organic carbon. Agroforestry systems in social forestry have shown potential to increase above- and below-ground carbon stocks compared to monoculture or open land farming systems (Nair et al., 2009). Social Forestry systems provide communities with opportunities to implement agroforestry practices, rehabilitate degraded land, and manage sustainable forests. The involvement of local communities often leads to more adaptive, responsive forest management. Case studies in several Social Forestry locations show success in increasing forest cover and biodiversity after communities were given management rights. For example, the Community Forestry (HKm) program in several areas has succeeded in rehabilitating critical land through planting local tree species and developing agroforestry (Hasannudin et al., 2022; Nurdin et al., 2023).

Although the potential of Social Forestry in soil management practicesto increase carbon stocks in the upper watershed is recognized, its success rate varies widely across locations. Adoption of land conservation practices at the farmer level in social forestry program areas is inconsistent and varies by context. Even in regions where formal management rights are provided under a social forestry program, many farmer groups do not effectively implement long-term conservation strategies. The lack of adoption of sustainable land management practices among Social Forestry participants is a complex issue driven primarily by economic insecurity, inconsistent institutional support, and tenure uncertainty. The program provides access to forest land but often fails to provide the holistic support needed for farmers to transition from traditional, short-term cultivation to long-term sustainable land management, such as agroforestry. The program provides land access but often fails to address the underlying drivers of unsustainable practices, which are the farmer's immediate need for income security and the lack of sustained, quality support to manage the technical and economic risks of transitioning to sustainable agroforestry systems. The primary concern is immediate survival and income, which clashes with the long-term nature of sustainable management. The literature highlights five interconnected factors that explain this trend: tenure and institutional conditions, knowledge and extension services, economic incentives and market access, social and organizational influences, and landscape and policy context (Pirard et al., 2015; Rakatama and Pandit, 2020; Wong et al., 2020; Ekarini and Koestoer, 2022).

The South Bukit Barisan National Forest (TNBBS) is a critical ecosystem in Lampung Province, Indonesia. It provides essential ecological services and supports local livelihoods. TNBBS is the upstream of various watersheds in Lampung and South Sumatera Provinces. The main and priority watersheds that flow through most of both provinces are Way Sekampung and Way Seputih watersheds. In the upstream areas of the watershed, changes in land use greatly determine the carrying capacity of the availability of ecosystem and hydrological services. Land use in the upstream area of the Sekampung River in Lampung, Indonesia, is mostly smallholder coffee plantations. In most of the protected forest lands in the upstream Sekampung watersheds, forest management concessions have been granted to communities since the 1980s. Protected forest management rights are mostly granted to farmer group associations (Gapoktan) under the Social Forestry program. Land management in upstream watershed regions is critical for maintaining ecosystem services, preventing land degradation, and ensuring sustainable agricultural productivity. Upstream watersheds are particularly vulnerable to soil erosion due to steep slopes, intense rainfall, and unsustainable land-use practices. Soil erosion not only reduces soil fertility but also leads to sedimentation in downstream water bodies, affecting water quality and aquatic ecosystems (Somura et al., 2018; Borrelli et al., 2020).

Evaluations are often site-specific, limiting generalization. There is a need for standardized indicators (socio-economic, governance, ecological outcomes) and robust longitudinal studies to measure long-term impacts. Policy changes, inconsistent subnational implementation, and vested interests (commercial concessions, local elites) complicate fair benefit distribution and program continuity. The political economy around land allocation and permits can undermine community claims. This research explored the extent of land management practices in smallholder coffee plantations in the upstream Sekampung watersheds by farmers participating in the Social Forestry program. The effectiveness of Social Forestry in achieving the goals of land conservation and increasing carbon stocks depends greatly on the level of adoption of appropriate sustainable land management practices in the field. Building awareness of long-term adoption at the farm level is the primary focus. Implementing sustainable land management s is obligated to long-term upstream watershed sustainability. Further exploration is needed to dig (1) the characteristics of social forestry program participant in the upstream of Sekampung as a basis for evidence of the institutionalization of sustainable land management from time to time; (2) the level of land management practices in different social, economic, and ecological contexts in Social Forestry program; (3) the main factors in decisions making for implementing land conservation in farmer level. An in-depth study of the level of land management in the Social Forestry program and its relationship to maintaining the sustainability of the upstream watershed is crucial to optimizing the role of the Social Forestry Program in achieving conservation and climate change mitigation goals.

Materials and Methods

Survey design

The research was conducted in Tanggamus Regency, Lampung Province, Indonesia, at the upstream of the Sekampung Watershed. There are two main sub-watersheds, namely Way Sangarus and Way Sekampung. The topography upstream is dominated by hilly and highland areas at altitudes between 200 and 1750 meters above sea level (masl). In the area bordering the Bukit Barisan Selatan National Park (TNBBS), the morphological unit of the volcanic cone has a fairly high elevation, which is around 500-1,750 meters above sea level, especially around Mount Rindingan. The average annual rainfall of the Sekampung Watershed is very high, at more than 2,350 millimeters (mm). The lowest is in August at 83 mm, and the highest is in December at 320 mm. Land use in Hulu Sekampung Watershed is dominated by primary forest, secondary forest, and dry land agriculture, as well as a water dam in Batu Tegi Dam, which serves as a power plant. This research took place in a protected forest area managed by farmers communally in the forest farmer’s association (*Gapoktan*) forum. The location of the protected forest is under the jurisdiction of the Batu Tegi Protected Forest Area Management Office (KPHL). Coffee-based farming is developing well through agroforestry systems, both simple and complex multistrata, as the main source of livelihood for people living in the upstream area (Somura et al., 2018; Fitriani et al., 2020).

The research location was in Air Naningan sub-district, Tanggamus. Two villages were chosen as a representation: Datar Lebuay and Sinar Jawa villages. Both villages lie between the Way Sangarus and Way Sekampung sub-watersheds. Sangarus and Sekampung rivers are the main water sources for Batu Tegi DAM. Respondent represents the land tenure of coffee farming. There were private and social forestry land tenure management. Most of the upstream Sekampung territory is protected forest, including all territory in Register 39, with an area of 58,162 ha. Air Naningan sub-district has a population of 30,185 people. There were 32 farmers' groups that had been licensed as social forestry program members in

Batutegi FMO jurisdiction. Social forestry territory reached 14,609.15 ha and involved 16,169 farmers. Respondents were represented as members of Mandiri Lestari, Sinar Harapan, and Wana Tani Lestari farmer's group associations. The management area was located upstream of Sekampung and Sangarus rivers. The total number of respondents is 125 farmers. The field survey was conducted from June to July 2024. The site location is relevant for describing upstream Sekampung land use related to Sekampung watershed management. Site location can be seen in Figure 1.

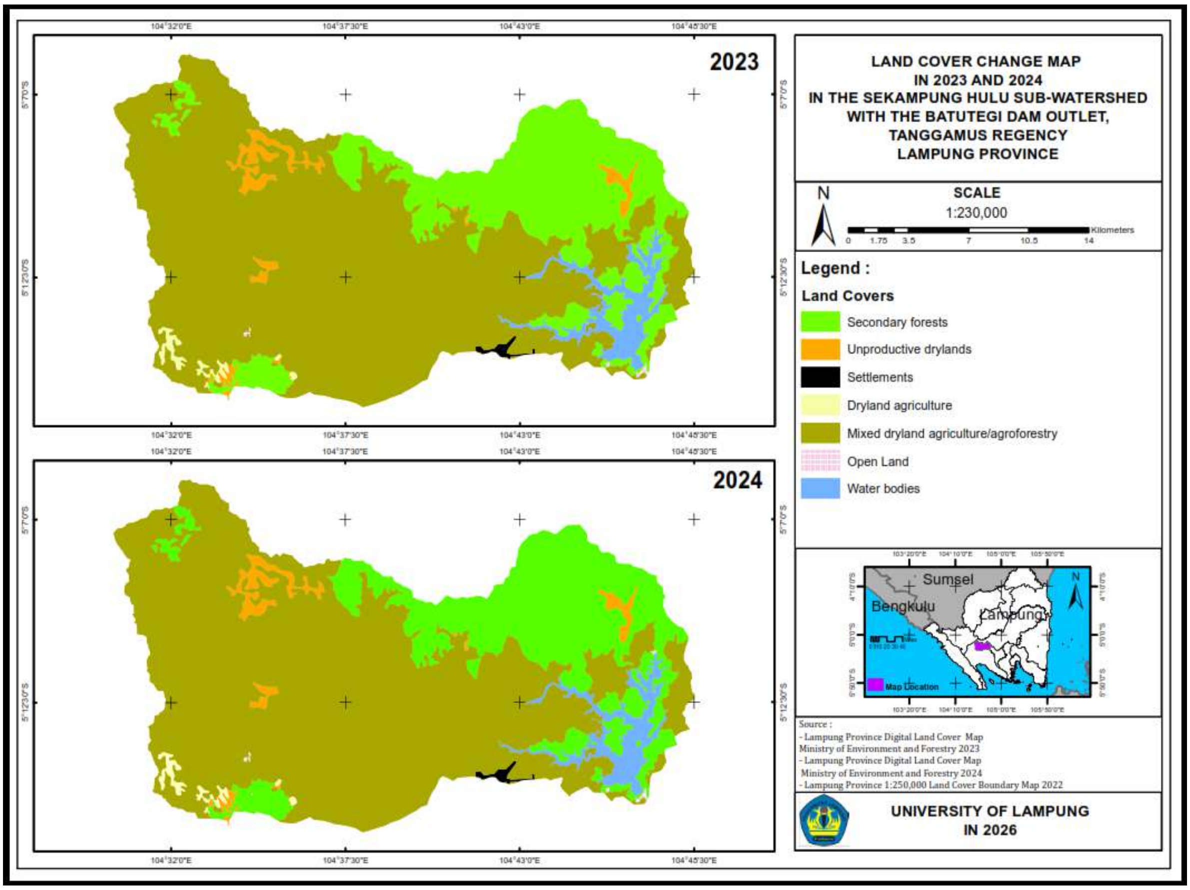

Figure 1. Research location, upstream Sekampung watersheds, Tanggamus, Lampung, Indonesia.

Sample size, techniques, and data collection

Data collection was conducted using a questionnaire. Information collection tools, such as surveys, were utilized to gather information. Interviews were conducted by enumerators trained in extracting information on farming and soil management. Prepared enumerators familiar with farmers' local dialect and traditions orally obtained information from respondents and completed the surveys. The selection of farmer respondents was conducted randomly on farmer members of the Farmers' association (*Gapoktan*) who obtained social forestry permits and were located in the upstream of the Sekampung Watershed. The farmers, moreover, undertake soil conservation measures mandated by the social forestry administration. A basic irregular inspection was used to distinguish the respondents. Farmers were randomly selected to provide information needed to analyze factors influencing decisions to adopt soil conservation methods. The test estimate included 125 respondents, selected for consideration. Essential information was obtained from respondents, including socio-economic and soil management implementation. The main investigation was conducted on land management activities grouped into biological and mechanical conservation technologies. Identification of biological conservation activities, also known as soil bioengineering, was conducted for shade planting practices, multiple cropping patterns, crop rotation, strip grass planting, mulching, use of organic/manure, and planting of hedge trees. Mechanical conservation investigated farmers' activities in preventing erosion/landslides and the rate of rainwater runoff by loading vents, rorak, ditches, dead-end channels, water channels, embankments, and building terraces according to the land contour. The questionnaire also investigated the social and economic conditions of farmers and the management of the main crop farming business. A list of questionnaires to trace the land management practices at the farm level is displayed in Table 1.

Table 1. List of questionnaires to trace the land management practices at the farm level.

No	Sustainable Land Management practices
1	Soil bioengineering
	a. Do you mulch your coffee plantation?
	b. Do you rotate crops other than coffee on your coffee plantation?
	c. Do you apply ameliorants/soil amendments/decomposers?
	Organic/composting:
	a. Compost/manure per coffee tree/year
	b. How many times do you make compost per year?
	c. Are weed removal results used for compost?
2	Mechanical engineering conservation
	a. Do crop lines cut across the contours of your coffee plantation?
	b. Do you plant grass strips across the contours of your coffee plantation?
	c. Do you build ridge terraces on your coffee plantation?
	d. Do you build bench terraces on your coffee plantation?
	e. Do you build gully control systems on your coffee plantation?
	f. Do you build dead-end drains or gullies on your coffee plantation?
	g. Do you build drainage channels on your coffee plantation?
	h. Do you build retaining dams or waterfalls on your coffee plantation?
	i. Do you build gabions on your coffee plantation?
3	Fertilization
	a. Fertilization per hectare of plantation, urea dosage applied per year
	b. Per hectare of plantation, Phonska dosage applied per year
	c. Per hectare of plantation, SP36 dosage applied per year
	d. Month of fertilization in the first semester
	e. Month of fertilization in the second semester
4	Weed control
	a. How many times do you weed per year?
	b. How many times do you cut weeds per year with a chopper?
	c. Spray weeds with herbicides how many times per year?
	d. Herbicide dosage per spray per hectare (ltr/ha):
5	Pest control
	a. What do you spray insecticide on your coffee trees to control?
	b. What do you spray fungicide to control?
	c. Spray insecticide and fungicide per year
	d. Insecticide/fungicide dosage per spray per hectare (mL/ha)
	e. How do you control coffee berry borer pests?

Data analysis

The first analysis was conducted through a literature review, tracing data and facts on the journey of social forestry at the research location. An analysis of soil management implementation at the farmer level was conducted by categorizing it into three levels: low, medium, and high. Descriptive statistics and cross-tabulation were conducted at the level of soil management implementation. Data collection on soil management practices was grouped into soil bio-engineering and mechanical land conservation. Soil bio-engineering practices include planting shade trees, using manure, mulching, and grass strips. Mechanical conservation includes creating terraces, vents/holes, water channels, embankments, and planting cross-contour lines on the land. The use of fertilizers and chemical pest control was also noted in farm management.

Analysis of decisions on the implementation of farmer soil conservation used a logistic regression model (Logit analysis). Logit analysis is considered for the reason (1) it has an easy interpretation of the Odds Ratio. One of the main advantages of logit regression is the direct interpretation of its coefficients as Odds Ratios. By exponentiating the coefficients (exp(β)), we obtain the factor change in the odds of an outcome occurring for each one-unit increase in the predictor variable (assuming other variables are constant). This interpretation is very intuitive and is often easier to understand for a wide range of audiences. Logit analysis does not require the Normality assumption. Logit regression does not assume that the error terms (or the underlying latent variables) are normally distributed. This can be an advantage when the normality assumption is difficult to satisfy. The logit model is based on the logistic distribution.

In soil management implementation, it is very useful to predict the likelihood of its adoption on coffee farmers' plantations (categorized by implementation level: low, moderate, high) based on various predictor factors (Kipsat et al., 2022). In soil management, it helps understand how a one-unit change in a predictor variable, for example, education level, affects the odds of soil management implementation being desirable or undesirable (Guteta and Abegaz, 2016; Sanou et al., 2017; Fitriani et al., 2018a; Sujakhu et al., 2018).

The independent variables taken into account included land area, number of coffee trees, coffee production, coffee age, farmer age, farmer education, experience, number of family members, coffee farming income, and household income. The logistic regression model formula is derived from the following equations.

$$\mathrm{Pi} = \mathrm{E}\left(\mathrm{Y} = \frac{1}{\mathrm{Xi}}\right) = \frac{\mathrm{e}\ \ln\left(\frac{\mathrm{Px}}{1-\mathrm{Px}}\right)}{1+\mathrm{e}\ \ln\left(\frac{\mathrm{Pv}}{1}-\mathrm{Px}\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(1)}$$

$$\ln\frac{\mathrm{Px}}{\mathrm{Pi/Px}} = \mathrm{Y} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(2)}$$

$$\mathrm{Y} = \beta 0+\beta 1\mathrm{X}1+\beta 2\mathrm{X}2+\beta 3\mathrm{X}3+\beta 4\mathrm{X}4+\beta 5\mathrm{X}5+\beta 6\mathrm{X}6+\mathrm{e} \ldots\text{(3)}$$

where: PX / Pi-Px = Odd ratio, is a comparison of the opportunity of people who are willing to apply soil management with the community who are not, P (Xi) = Soil management (Y=soil management implement = 1, if No, then the value is 0) P (xi) = Yp

$\beta 0, \beta 1, \beta 2, \ldots, \beta n$ = regression coefficient

X_1 = Land (ha)
X_2 = Coffee age (years)
X_3 = Farmer's age (years)
X_4 = Farmer's education (years)
X_5 = Farmer's experience in coffee farming (years)
X_6 = Family members
e = Error

Results and Discussion

Socio-demographic conditions of social forestry participants

The socio-demographic characteristics of farmers provide important insights into how the main actors make decisions and carry out farming management activities in the social forestry system in protected forest areas in Indonesia. Farmer involvement in the social forestry program is assessed by the duration and motivation for participation (Table 2).

Most farmers (62%) have participated in the program for more than six years. The Forestry Service and the protected forest management office continuously evaluate and monitor participation and fulfilment of social forestry program obligations. Program evaluations are conducted annually, and program permits are valid for a five-year period. The primary motivation for farmers to participate in the program is collective participation with farmer groups or community forestry groups. In general, indicators of socio-economic conditions are represented by age, education, experience, number of family members, and ownership or control of land assets. The oldest farmer is 90 years old, and the youngest is 23 years old.

Table 2. Social forest program joint duration.

Duration of Forest Program	(%)
<1 year	1.45
2-3 years	18.84
4-5 years	17.39
>6 years	62.32
Main drivers in joining the Forest Program	
Forest Agency Program	14.49
Follow the other farmers	52.17
Forest land management rights	33.33

On average, respondents are 42 years old and are in the productive age range. The age of farmers is a measure of their potential and physical and mental abilities to farm with enthusiasm, actively, and productively. Education is an indicator of the quality of human resources at the farmer level, serving as the main driver of creativity, innovation, and the adoption of new technologies, enabling farming to run optimally and more effectively. Education is human resource capital that greatly determines the success and achievement of social, economic, and environmental welfare. There are still farmers who have not received formal education, the oldest age (90 years), but are still actively farming. On average, farmers have a junior high school education.

Farmers have an average of 16 years of experience, and the most experienced are 47 years. Farming experience is one of the determining factors for farmers' success in managing their businesses effectively. Experience is an important source of learning that produces broader and deeper knowledge, insight, and skills in carrying out various agricultural activities. The cross-visualization of the age, education, and experience conditions of farmers is presented in Figure 1.

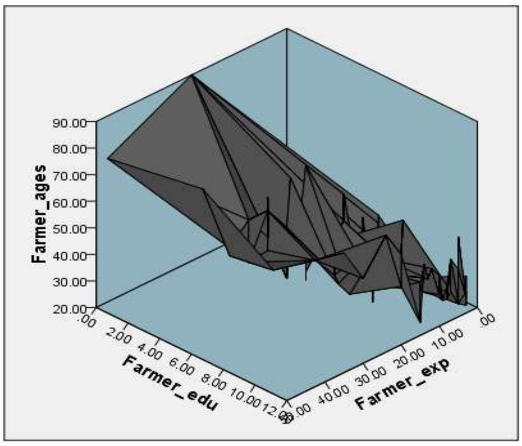

Figure 1. Cross-visualization of farmer age, education, and experience conditions.

Figure 1 shows that farmers at the research location are concentrated in the age group under 40 years, have formal education equivalent to junior high school (8 years), and have less than 20 years of experience. Age, education, and farming experience significantly influence farmers' decision-making patterns. Farmers with a productive age range, adequate education, and experience will have a level of maturity in allocating resources, implementing innovations, and choosing access to sustainable technologies, including conservation practices on their farms (Hastanti and Susanti, 2019).

The average area of agricultural land is 2.07 ha. Most farmers have access to land ownership with clan/private status and social forestry land. The land area of farmers is in the range of 0.75 ha to 7.5 ha. The land area of the majority of farmers is small-scale (<2 ha). Land ownership of >5 ha is owned by less than 3% of farmers. Limited access to land ownership, inheritance patterns, or land fragmentation occurs due to division among the next generation. Ownership of large amounts of land is very rare for farmers. Small-scale farming businesses face problems with limited capital, access to land, or business patterns that are more family-based.

The presence of land on sloping topography in upstream river areas and protected forest areas will determine the pattern, choice of plants, and land management, as well as the application of GAP (good agricultural practices), which will affect the level of production of the main farming business. The main farming business of the respondent farmers is coffee, with multiple cropping of pepper, banana, and seasonal vegetable plants. Farmers in the social forestry system are obliged to plant forest trees. Therefore, in the area of farmer's land, vegetation of various types of commercial plants and forest plants is collected. Biologically, commercial coffee and pepper plants require shade, which is provided by forest tree stands. Land use patterns with various choices of commercial commodities and forest trees can be seen in Figure 2.

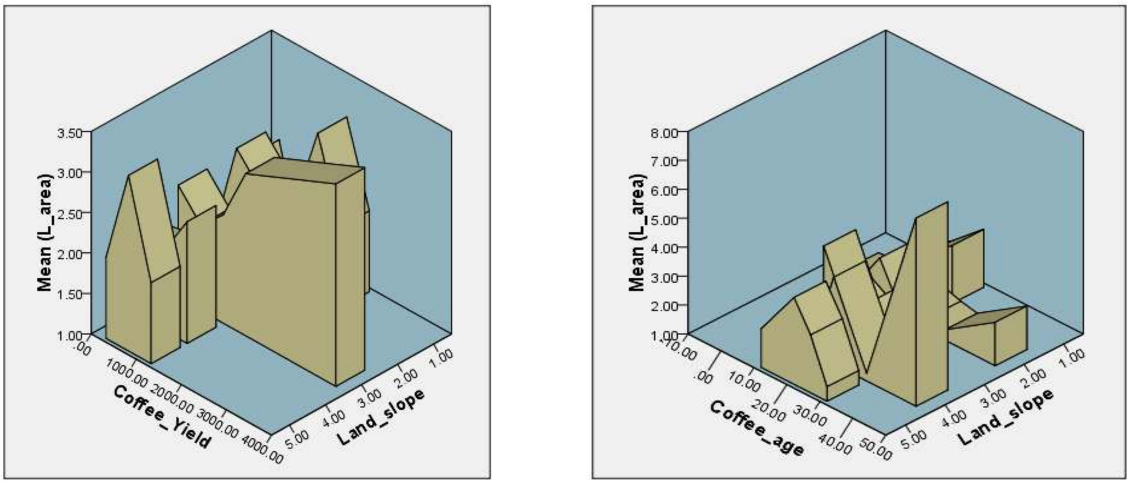

Figure 2. A cross-visualization of land area, land slope, and coffee production of farmers.

Figure 2 presents a cross-visualization between land area, land slope, and coffee production of farmers. Visually, it can be seen that farmers with a land area of less than 2 ha are on a slope that is in the sloping land category (level 3: slope above 15%). The resulting coffee production is concentrated at an angle of less than 1 ton per ha from an average coffee planting of less than 2,500 trees per ha. Farmers' land is used not only for coffee planting but also for multiple cropping plants and tall-stand plants required in the social forestry program.

The farmer involved in the Social Forestry program in the upstream Sekampung area shows a clear pattern of social change over time. In the early stages, the main participants were farmers with little formal education, who were not very involved in organizations and relied mostly on farming to meet basic needs. But today, the group includes more organized people involved in various economic activities and actively part of local groups and institutions such as farmer groups, farmer’s association groups (Gapoktan), and collaboration units with the forestry office. These changes show that the Social Forestry Program is more than just giving people access to land—it also helps communities become stronger and more capable, leading to long-term changes in how they manage forests and make decisions together.

Sustainable land management practices at the farm level

These are the on-the-ground technical measures designed to prevent land degradation, enhance productivity, and maintain ecosystem services. Sustainable land management (SLM) is crucial in addressing land degradation. SLM ensures the optimal use of the land's resources as well as underpinning ecosystem services – for the benefit of present and future generations. SLM emphasizes practices that improve soil health and water retention. SLM activities at the farmer level are traced into two categories, namely biological and mechanical conservation activities. Biological conservation (soil bioengineering) carried out by farmers includes shade trees/mixed trees, land mulching, soil composting/ameliorant, and grass strip plantings with *Pennisetum purpureum* cv. Mott. Based on the data collected, farmers were observed carrying out the soil bioengineering practices. Table 3 shows the status of farmers based on the type of biological conservation they practice. Most farmers plant shade trees (57.6%) and grass strips (20.8%).

Table 3. Soil bioengineering adoption at the farmer's level.

Soil bioengineering	**Participant Response**			
	Not adopt yet	**Yes/Adopter**	**Total responses**	**Total farmers**
Shade trees/mix trees	53	72	125	125
Mulching on land	69	10	79	125
Soil composting/ameliorant	62	15	77	125
Grass strip plant planting	52	26	78	125
Type of grass strip: *Pennisetum purpureum* cv. Mott				

Planting shade trees is crucial as a demonstration of agroforestry implementation. Various tree species used as shade trees in coffee plantations are listed in Table 4. Based on records of various tree species found in coffee plantations, it can be seen that farmers' use of shade trees constitutes a complex agroforestry system, characterized by an agroforestry pattern (Ahmad and Goparaju, 2017; Fitriani et al., 2018b). The characteristics of complex agroforestry systems that are implemented at the farm level are categorized as multistrata or complex systems. The agroforestry structure features multiple vertical layers of vegetation, including tall trees (timber and fruit), mid-canopy trees (for shade or fruit), understory shrubs (coffee and cocoa), and ground-level annual crops/herbs. The high diversity of species across multiple categories within woody perennials (multiple species of trees, shrubs, and palms) and non-woody components (food crops, lianas, herbs, seedlings, and sometimes livestock). The complexity provides robust ecological stability and superior environmental services compared to monocultures.

Table 4. Tree species as shade trees found in coffee plantations.

Tree spesies	**Names of tree**	**Farmer's adopter**	**Average plants in land**
MPTS	Jengkol (*Archidendron pauciflorum*)	73	18
	Pete (*Parkia speciosa*)	80	9
	Durian	51	8
	Avocado	44	17
	Candlenut (*Aleurites moluccana* (L.) Willd.)	12	19
	Cloves (*Syzygium aromaticum* (L.) Merr & Perry)	7	18
	Rubber	2	87
Forest wood	Batel nut (*Areca catechu*)	30	93
	Dadap (*Erythrina variegata*)	16	18
	Cempaka (Magnoliaceae)	15	10
	Sonokeling (*Dalbergia latifolia*)	11	20
	Medang (Phoebe)	5	7
	Mahoni (*Swietenia macrophylla*)	5	18

The diversity of trees on the farmer's land provides flexible products for smallholders; if the market price of one commodity (e.g., coffee) falls, income can be sustained by other products (e.g., fruit or timber), thereby increasing economic resilience. This arrangement allows for efficient utilization of light, water, and nutrients. Due to the large volume of woody biomass and continuous organic matter input, they have a high potential to sequester atmospheric carbon in both above-ground vegetation and soil (Evizal et al., 2016). By integrating trees into coffee cultivation, the land-use system transitions from an erosive monoculture to a productive, multifunctional landscape that ensures long-term environmental protection and economic stability, making it an essential component of SLM in vital watershed areas. Agroforestry is crucial for preserving this balance. The greatest benefit of coffee agroforestry in a watershed is its role in water management, which is significantly better than conventional monoculture. The multi-layered canopy (shade trees, coffee, ground cover) and extensive root systems intercept rainfall and bind the soil, drastically reducing surface runoff and soil erosion (Kuswadi and Fitriani, 2021). Previous research confirmed that coffee agroforestry helps keep erosion rates under control (Kuswadi et al., 2023).

The shade trees often provide secondary products, such as timber, fruit (e.g., durian and jackfruit), fuelwood, and fodder. This provides farmers with multiple income streams, increasing their economic security and reducing their reliance solely on volatile coffee market prices. Case studies in Sumatra, Indonesia, show that coffee agroforestry systems have a positive, significant impact on improving both the economic and environmental benefits for smallholder farmers (Valencia et al., 2014; Hakim et al., 2019). Farmers participating in social forestry are obligated to plant and maintain forest trees on the concession lands they manage (Evizal et al., 2016; Davis et al., 2017; Cerda et al., 2020; Solis et al., 2020).

Grass strips are a valuable Sustainable Land Management (SLM) practice in coffee farming because they serve distinct, yet complementary, roles in reducing soil erosion and supporting underground biodiversity. Grass strips, when installed along the contour of sloped coffee fields, are highly effective in mitigating soil erosion by interrupting the flow of surface water. The dense foliage and stems of the grass act as a physical filter and barrier across the slope. When rainfall runoff encounters the grass strip, its velocity is significantly reduced. This lowered kinetic energy means the water has less power to detach and transport soil particles. As water slows, it loses its capacity to carry suspended soil particles (sediment). The grass strip functions as a natural sediment trap, causing soil particles and organic matter to settle out behind it.

Over time, this trapped material builds up to form small, natural terraces (or bench terraces), effectively flattening the slope and increasing the land's stability. The root systems of the perennial grasses create and maintain soil macropores (channels and voids). These channels improve water infiltration into the soil, reducing the volume of water that flows over the surface as runoff. Less runoff translates directly to less erosion. The grass's extensive, fibrous root network acts like a net, tightly binding the soil particles together. This high root density increases the soil's resistance to detachment from rainfall impacts and runoff shear forces. Grass strips provide a less disturbed, non-tilled habitat, creating an ideal environment for soil organisms and contributing to overall soil health in the surrounding coffee plot. In summary, grass strips serve a dual role: as an engineering solution to physical erosion and as a biological solution to enriching the soil ecosystem, making them a crucial SLM technique for sustainable coffee farming, particularly on sloping lands (Harari et al., 2023; Kuswadi et al., 2023).

Although only a few farmers use compost and mulching, this shows that farmers are becoming more aware of the need to return organic material to the land. Only a small percentage of farmers mulch and use ameliorants (9.60%) (Table 5). The rare application of compost fertilizer in coffee farming, from the farmer's perspective, is primarily driven by economic, logistical, and technical challenges. The leaf litter and increased soil organic matter (SOM) resulting from tree biomass create a porous soil structure.

Table 5. Composting activities by farmers.

Composting activities	Many farmers do
Compost/manure per coffee tree/year	
(a) not given	48
(b) 1-2 kg	10
(c) 3-4 kg	1
(d) 5-8 kg	0
(e) 9-10 kg	1
Total participant	60
Percentage of farmers who do (%)	9.60
Composting for a year	
Making compost per year?	
(a) 0x	69
(b) 1x	10
(c) 2x	1
(d) 3x	0
(e) 4x	0
Total participant	80
Percentage of farmers who do (%)	8.85
Weed for compost	
No	56
Yes	20
Total participant	76
Percentage of farmers who do (%)	16.00

While the use of compost, mulching, and ameliorants is crucial for improving soil quality, few farmers implement them. For smallholder coffee farmers, whose livelihoods are often fragile, the barriers to compost adoption are perceived as significant risks to their productivity and income. The decision is heavily influenced by the immediate financial and labor trade-offs. Composting requires significant time and physical labor for collecting raw materials (like coffee pulp, husks, or manure), constructing the piles, regular turning/aeration, and then transporting and applying the bulky finished product to the coffee trees. Many small-scale farmers, especially those with aging populations or labour shortages, view this as prohibitive compared to spreading concentrated granular chemical fertilizer. Even if farmers do not make the compost themselves, sourcing and transporting the large volumes of compost required to adequately fertilize a coffee field is far costlier and more difficult than purchasing and moving small bags of concentrated mineral fertilizer. Smallholder farmers often lack the capital to invest in equipment (like shredders or trailers) or to hire the necessary labor for a large-scale composting operation. This is due to the significant disparity in mastery of conservation technologies among farmers (Udawatta et al., 2019; Mamo et al., 2022). Several case studies show economic gains are concentrated where market linkages and business development support exist.

In short, farmers feel that while compost is good for the soil in principle, the immediate economic pressure to maintain high, consistent yields with limited labor and capital pushes them toward the convenience and speed of chemical fertilizers. It is a complex issue, but the difficulties in adopting compost on farmland, particularly in mountain areas, can be categorized into several key barriers. These constraints apply to farmers across many regions, not just mountainous ones. A shortage of the necessary woody biomass or other organic matter can hinder on-farm composting. Mountain regions or upstream watersheds face amplified challenges due to their unique physical and socio-economic characteristics. It often consists of small, widely dispersed, and steep terraced fields. This makes it extremely difficult, or even impossible, to use machinery to turn compost piles or mechanically spread the finished product. Limited road access and poor infrastructure in remote mountain areas make importing commercial compost or even necessary composting equipment costly and impractical. Many smallholder mountain farmers prioritize immediate, reliable yields for subsistence. The risk, time, and delayed return associated with switching to compost are often seen as too high compared to the guaranteed, short-term boost from chemical fertilizers. Meanwhile, the soil mechanical conservation practices generally applied by farmers are shown in Table 6. Soil mechanical conservation adoption responses at the farmer's level are displayed in Table 6.

Table 6. Soil mechanical conservation adoption responses at the farmer's level.

Mechanical land conservation	**Participant Response**			
	Not adopt yet	**Yes/Adopter**	**Total responses**	**Total farmers**
Planting according to the contour of the land	44	35	79	125
Making a bench terrace	66	12	78	125
Creating a chasm boundary	60	18	78	125
Ditch, vent, a gutter end channel	61	18	79	125
Drainage line	44	35	79	125

Mechanical land conservation practices implemented by farmers generally include planting along the contours of the land, constructing bench terraces, creating chasm boundaries, ditching, venting, installing gutter end channels, and installing drainage lines. The number of farmers actively engaging in mechanical conservation activities remains low (<30%). Farmers in higher-slope or erosion-prone areas adopt more labour-intensive measures such as terracing, check dams, and vegetative barriers, driven by immediate erosion risks and the visible benefits of soil retention. Terracing and bunds are constructed steps or earthen barriers across slopes to interrupt water flow, reducing runoff velocity and soil loss. Rainwater harvesting by check dams, ponds, or trenches set to capture and store runoff water for later use or to increase groundwater recharge. Planting permanent vegetation along rivers and streams to filter pollutants from runoff, stabilize banks, and provide habitat is a riparian buffer zone (Kuswadi and Fitriani, 2021).

Implementing mechanical conservation technologies requires high costs and labour, resulting in only a small number of farmers being aware of and adopting these technologies (Sukwika, 2019). Both these structural and vegetative (soil bioengineering) measures control water flow and erosion, especially on sloped land. The main challenge is to address the increasing pressure on natural resources, particularly water and arable land. Exploring technological advancements that can boost food production in alignment with the growing soilless production system is a proficient approach and a significant contribution to food security (Majdalawi et al., 2023).

The level of sustainable land management practices

The level of implementation of sustainable land management based on the answers to the questions (Table 1) was then tabulated to obtain a score for the level categorization. Based on the level of implementation of land conservation management, both mechanical and biological, it is further categorized into levels: (1: low; 2: moderate; 3: high). The level of implementation of soil bioengineering (SBO) and mechanical soil engineering (SME) activities can be seen in Table 7.

Table 7. The level of land sustainable management adoption.

Level conservation adoption	**Farmer**	**(%)**
Soil bioengineering (SBO)		
Low	50	40
Moderate	48	38
High	27	22
Mechanical soil conservation (MSE)		
Low	67	54
Moderate	50	40
High	8	6
Total respondent	125	100

The implementation rate of SBO land conservation in the medium-to-high category shows encouraging progress, with 60% of farmers implementing. However, compared with the implementation rate among SMEs, the rate among farmers in the medium to high category is only 46%. This fact provides significant capital to institutionalize land conservation technology in the upstream watershed. Farmers with a higher level of implementation can become pioneers of advanced farmers, representing social capital with great potential to encourage other farmers to continue practicing sustainable land management.

The social capital of farmer resources plays a significant role in improving the quality of farmer human resources. The transfer of knowledge and skills among farmers greatly requires social capital as an internal strength. This is especially important given the high number of farmers at low levels (40%-54%). This is related to the farmers' background. Farmers lack conditions due to a convergence of economic, technical, and social constraints. Economic limitations are significant, as these practices often require high initial labour and material costs (e.g., excavating terraces or purchasing large volumes of vegetative material) and provide delayed returns on investment, making them prohibitive for resource-poor smallholder farmers. Technical constraints arise from the need for specific knowledge and skill—farmers often lack adequate training to correctly design structures based on precise slope measurements and soil type, leading to poorly built systems that fail during heavy rainfall and discourage future adoption.

Internal collaboration is needed within farmer groups and farmer group associations to continuously improve the level of knowledge and skills of sustainable land management among their member farmers. Furthermore, support from relevant agencies, environmental observer institutions, and universities is crucial in strengthening the capacity and quality of farmer human resources. The successful implementation of soil bioengineering and mechanical conservation is intrinsically linked to farmer education and farm experience. It is fundamentally linked to farmer education and farm experience because these systems require a blend of technical accuracy and long-term ecological stewardship. The following is a cross-tabulation of the level of conservation implementation at various levels of education and farming experience. A cross-visualization farmer's education, experiences toward conservation level present in Figure 3.

Farmers with a high school education implement higher levels of land conservation, both biological (SBO) and mechanical (SME), than farmers with a primary education. The successful implementation of soil bioengineering (e.g., shade trees, vetiver grass strips, live barriers) and mechanical conservation (e.g., terraces, bunds) is intrinsically linked to farmer education and farm experience, as these practices require precise site-specific knowledge, skillful application, and a long-term maintenance commitment.

While mechanical structures often demand specific technical skills (e.g., calculating slope, accurate levelling) best acquired through structured education and training, bioengineering practices rely heavily on local ecological knowledge—a key component of farm experience—for selecting the right species, optimal planting times, and managing the live materials for maximum effectiveness. A well-educated farmer better understands the underlying hydrological principles and the rationale for maintenance, enabling them to adapt and sustain the structures effectively, transforming simple structures into durable, long-term Sustainable Land Management (SLM) investments that integrate successfully with the farm's unique environment.

Similarly, farmers with more than 20 years of farming experience implement conservation measures more often (Guteta and Abegaz, 2016; Hasannudin et al., 2022). Overall, soil conservation adoption is shaped by an interplay of biophysical necessity and socio-economic capacity, indicating the need for site-specific and community-specific intervention designs. Furthermore, the discussion focuses on the traces of key success factors that influence farmers' adoption of soil management/land conservation practices, along with explanations and evidence from the literature. Farmers' access to different "livelihood capitals" (natural, social, financial, physical) strongly influences adoption. Farmers are more likely to adopt conservation practices when they feel confident that they will retain long-term access to the land (Huang et al., 2020). Secure tenure encourages them to invest in labour-intensive, long-term measures (e.g., terraces, bunds) (Kuswadi et al., 2023).

Coffee farming practices at the farm level

The implementation of Good Agriculture Practices (GAP) coffee by farmers can be traced to plant and land management activities. Not all farmers responded to the coffee maintenance and land management interviews. The number of farmers responding ranged from 37.60 to 64.48%. Those who responded were also unsure whether they were engaging in GAP activities. The main reason for this was that they did not remember the details of the coffee GAP and their land management practices. Most farmers use inorganic fertilizers on coffee farms. Farmers use organic fertilizer materials at a range of doses from 50 to 200 kg/ha, with an average application frequency of 2 times a year. Meanwhile, farmers' efforts to control plant pests generally use herbicides and pesticides with intensity (2-4 times per year). Organic fertilizer materials and plant pest controls remain the choice of farmers for increasing coffee production. The data in Table 8 show the intensity of fertilization frequency and volume, and the OPT control carried out by coffee farmers. Table 8 shows the maintenance of coffee farming practices in the field.

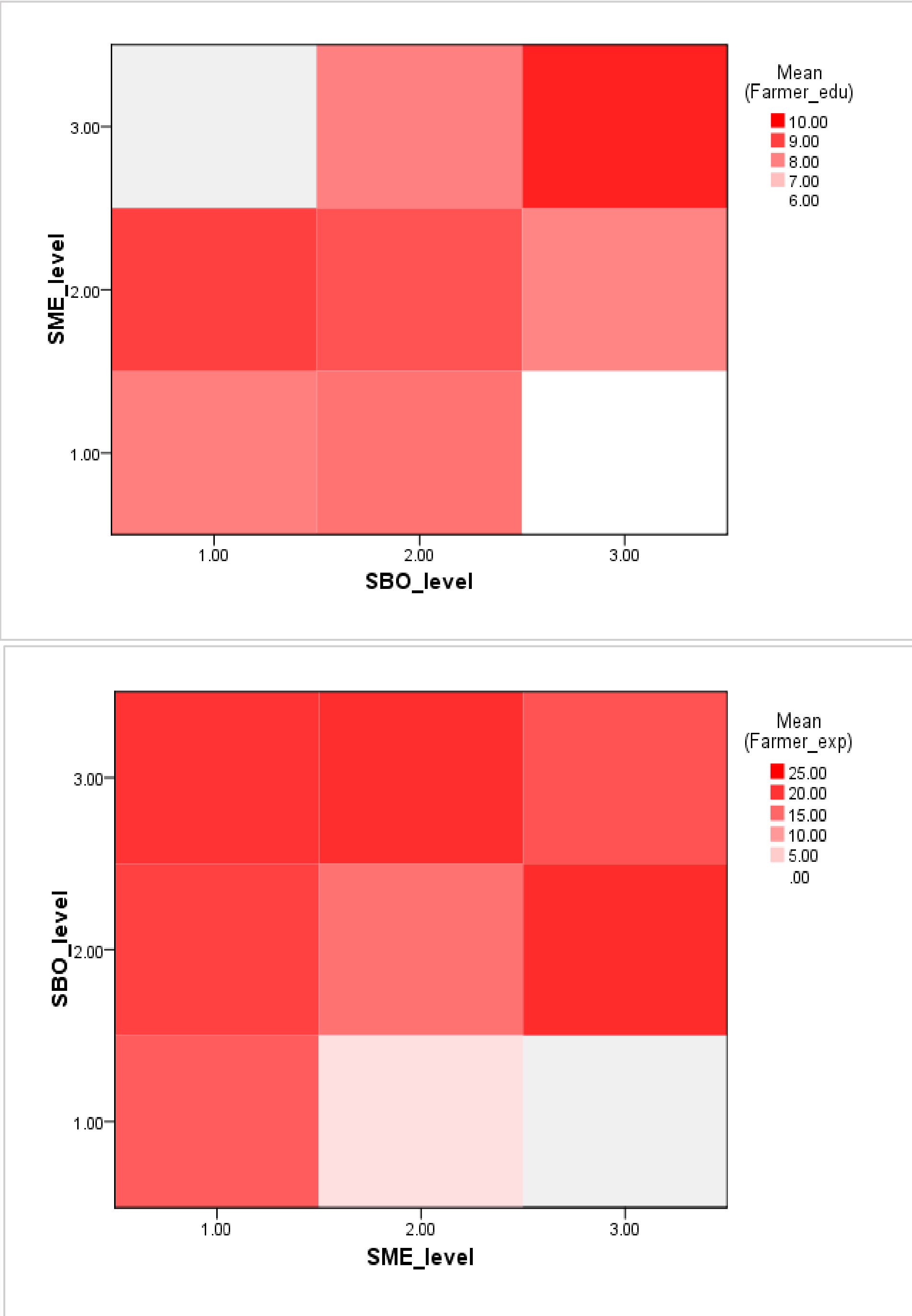

Figure 3. A cross-visualization farmer's education, experiences toward conservation level.
SBO: soil bioengineering level: (1: low; 2: moderate; 3: high), SME: Mechanical soil bioengineering.

Table 8. Maintaining coffee farming practices in the field.

GAP Practices	Participant Response			
	Not adopt yet	Yes/Adopter	Total responses	Total farmers
Organic Fertilizers	62	15	77	125
Inorganic Fertilizers				
a. Urea	55	70	77	125
b. Phonska	71	54	72	125
c. SP36	118	7	47	125
Weed control	44	35	79	125
Pest control	46	32	78	125

Coffee farmers primarily prefer using inorganic fertilizers over compost. From the smallholder farmer's perspective, this preference is driven by several key practical factors. Inorganic fertilizers like Urea (Nitrogen), Potassium, and Kalium (NPK compounds) contain nutrients in highly concentrated, water-soluble forms. Inorganic fertilizers provide a fast, predictable, and logistically simpler path to securing the critical yields that sustain a coffee farmer's livelihood. However, coffee farmers overwhelmingly prefer using chemical methods (herbicides and pesticides) for controlling weeds and pests because they offer an immediate, effective, labour-saving, and economically predictable way to protect their critical yields.

From the smallholder farmer's perspective, the decision is a practical necessity driven by the need to provide a rapid, visible control of weeds or pests. This is crucial when an infestation (like Coffee Berry Borer or Leaf Rust) or a sudden weed outbreak threatens the current harvest. Organic methods are often slower and less consistently lethal. On larger or widely dispersed farms, particularly in hilly areas, chemical spraying is the only practical and efficient way to quickly cover the entire area, preventing infestation from spreading. Weeds are cited as the number one barrier for organic coffee farmers due to the labour requirement. Farmers are generally risk-averse. They still view the use of proven chemical products as "insurance" against devastating yield losses (which can range from 30-70% from uncontrolled weeds) caused by unpredictable pest or disease outbreaks.

Plant cultivation significantly impacts coffee productivity. With complex agroforestry patterns, coffee productivity in the study area reached around 0.50-0.70 tons/ha. This is relatively low compared to monoculture coffee or the national average, which can reach more than 1 ton/ha. However, unlike monoculture patterns, agroforestry allows farmers to gain income from various types of shade-grown crops that produce food and spices, thus securing their income.

Logistic model of soil conservation adoption at the farmer's level

The level of knowledge and skills of farmers regarding land conservation technology is largely determined by the age, education, and experience of farmers. Education of farmers and their exposure to technical guidance are critical. Education level, farming experience, and contact with extension services significantly affected the adoption of improved structural conservation measures (Wordofa et al., 2020). Using a logistic regression approach, the key factors for implementing land conservation at the research location are presented in Table 9.

Table 9. The probability of implementing soil conservation adoption at the farmer's level.

Parameter			Estimate	Std. Error	Z	Sig.	Odd Ratio
LOGIT[a]	Coffee_age		-0.025	0.000	-267.312	0.000	0.97532
	Farmer_ages		0.046	0.000	553.331	0.000	1.04695
	Family_mem		0.179	0.001	331.020	0.000	1.19551
	L_area		0.154	0.001	287.268	0.000	1.16598
	Farmer_edu		0.240	0.000	722.993	0.000	1.27089
	Farmer_exp		0.049	0.000	403.977	0.000	1.05053
	Intercept[b]	0	-13.866	0.006	-2328.92	0.000	
		1	-13.737	0.006	-2394.09	0.000	

$$Y= -13.73-0.02X1+0.05X2+0.18X3+0.15X4+0.24X5+0.05X6+e\ldots$$

X_1 = Land (ha)
X_2 = Coffee age (years)
X_3 = Farmer's age (years)
X_4 = Farmer's education (years)
X_5 = Farmer's experience in coffee farming (years)
X_6 = Family members
e = Error

Farmers' willingness to implement land conservation is significantly determined by variables such as coffee plant age, farmer age, family member, land area, farmer education, and farmer experience. The logistic model can be interpreted using odds-ratio values. For variables that show statistical significance at a confidence level above 95%, the odds ratio value is meaningful as a key variable. Among these, education and land area have the biggest impact. The odds ratio for education is 1.2, indicating that each additional year of schooling increases a farmer's likelihood of using land conservation methods by 1.2 times. This suggests that educated farmers are better at understanding the benefits of conservation, recognizing the long-term advantages, and being open to new ideas for managing their land. The odds ratio for land area is 1.19, indicating that for every additional hectare a farmer owns, they are 1.19 times more likely to use conservation practices. Larger farms give farmers more space to build things like terraces, plant trees, or use other natural barriers to protect the soil. They also have more to gain from long-term land protection, which makes them more willing to try new methods.

The use of logistic regression to quantify the influence of factors such as education, land size, farming experience, and crop age provides robust analytical grounding. The study underscores how smallholder decisions—shaped by awareness, socio-economic dynamics, and institutional support—directly affect ecological resilience in upstream watershed areas. Overall, these findings show that whether a farmer uses land conservation is not just a matter of chance. It is influenced by a mix of education and experience, age and family size, the age of the coffee plants, and the amount of land they own.

Farmers who are better educated, have more experience, or manage bigger farms are more likely to want and be able to adopt conservation practices. This strong evidence supports the need for focused efforts to help farmers learn more, gain hands-on experience, and get support, especially for those with large but vulnerable farms. This adds practical and theoretical value to ongoing global efforts to enhance climate-resilient agricultural landscapes. These actions can greatly improve the use of land conservation practices in areas of Social Forestry.

The model has identified the key determinants of adoption. The next step is to translate these findings into context-specific, evidence-based strategies (Aprilia et al., 2026). The results show that farmer's internal conditions (age, education, and experience) fully explain the opportunity in conservation adoption. Then the training, knowledge, or extension access is necessary and significant as part of a multi-year support program to strengthen the farmer's capacities. Practical knowledge and ongoing technical help are very important. Many farmers lack proper training in soil and water conservation methods that work best for their area, or in designing agroforestry systems that fit local conditions, such as slope, soil type, and crops. Short, single-day training sessions do not make much difference. Successful projects use real-life examples, field experts, and continued support even after permits are approved. Non-governmental organizations and extension services play a big role in these cases.

The examination of land management within Indonesia's Social Forestry Program and specifically in the upstream Sekampung watershed generates empirical insights from a region and institutional framework that are insufficiently documented yet highly relevant to global discussions on community-based natural resource management. This integrated perspective enriches the interdisciplinary literature on sustainable agriculture and watershed management. How farmers' demographic characteristics, socio-economic conditions, and ecological contexts collectively shape soil conservation behaviour. Conservation practices often require work or upfront costs and take time to show results. When families involved in social forestry can sell their agroforestry products in high-value markets, receive payment for the environmental benefits they provide, or secure loans to cover initial costs, they are more likely to adopt these practices. On the other hand, if there is no way to join with other farmers, weak connections to buyers, or poor transportation, people do see enough benefit from investing in long-term conservation. Many studies across regions show that greater market access and supply chain support lead to broader adoption of these conservation methods (Kuswadi et al., 2023; Yang et al., 2024). The study provides valuable evidence that policy-driven interventions can catalyze local social change—an important gap in the literature on environmental governance.

Conclusion

The Social Forestry Program in the upstream Sekampung watershed has led to significant social transformation, developed varied conservation practices, and highlighted key factors affecting farmers' decisions to adopt them. The results from the logistic regression show that farmers are more or less likely to use land conservation practices based on several key factors: Coffee age, Farmer age, Family member, Land area, Farmer education, and Farmer experiences.

The education variable will increase the opportunity for implementing sustainable land management. Sustainable land management practices vary significantly across different social, economic, and ecological settings in the Social Forestry landscape. Farmers in higher-slope or erosion-prone areas adopt more labour-intensive measures such as terracing, check dams, and vegetative barriers, driven by immediate erosion risks and the visible benefits of soil retention.

The findings indicate that expanding sustainable land management efforts depends on strengthening institutions, providing ongoing technical support, ensuring financial accessibility, and fostering coordinated action at the landscape level. Applying these strategies will boost ecological resilience, enhance farmer livelihoods, and ensure the long-term success of Social Forestry through sustainable forest management.

Acknowledgements

The authors thank Okayama University and KAKENHI Grant No. 22KK0093 (Fund for the Promotion of Joint International Research (Fostering Joint International Research (B) for FY2022) Japan for organizing this international collaborative research activity with Politeknik Negeri Lampung and Universitas Lampung. The authors also extend their gratitude to all the Gapoktan (Farmer Group) officials in Air Naningan District and the Batu Tegi Forest Management Unit (KPH).

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