

Case Study – Land Suitability Assessment for Coffee Agroforestry in Selobanteng, Situbondo, East Java, Indonesia

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ABSTRACT

Coffee is an important agricultural commodity with both economic and ecological importance. Before cultivating coffee, land suitability analysis is essential to establish a scientific basis for the initiative's success. This study aimed to assess the suitability of land for coffee agroforestry development in the community forest of Selobanteng, Situbondo, East Java, using GIS-based spatial analysis and the agroecological matching method, as well as to identify key constraints. The results of the GIS analysis, based on altitude, temperature, and slope, indicated that the community forest was classified as unsuitable (N) for Arabica coffee but suitable for Robusta coffee (S1, S2, S3). Furthermore, the actual land suitability class determined using the matching method for Robusta coffee was not suitable (N), with the most critical limiting factor being the number of dry months, which affected water availability. Insufficient rainfall, with 5 to 9 dry months annually, could hinder coffee growth and productivity. Other limiting factors included low organic carbon levels and steep slopes. However, if the most severe limiting factor was mitigated, the potential land suitability for Robusta coffee was predominantly classified as S3 (marginally suitable). Several recommendations are provided in this study to overcome these constraints and address associated agroecological and socioeconomic challenges.

Key words: Agroecological suitability; coffee agroforestry; GIS; matching method; robusta.

1 INTRODUCTION

Selobanteng Village, covering about 1,165.5 hectares in the Banyuglugur Sub-district, Situbondo Regency, East Java Province, served as the site of a ten-year collaboration between the community and the private sector from 2008 to 2018, aimed at restoring degraded land within the community forest. Around 100,000 trees, primarily teak (*Tectona grandis* L.f.) and gmelina (*Gmelina arborea* Roxb. ex Sm.), were planted, resulting in increased vegetation cover as confirmed by normalized difference vegetation index (NDVI) analysis. However, economic pressures led to early harvesting by local residents starting in the seventh year, causing a decline in vegetation cover (Hapsari et al., 2023). A follow-up program is required to address these challenges while ensuring both ecological and economic benefits. The previous tree-planting initiative provides a foundation for developing coffee-based agroforestry systems. Coffee is a commercially valuable crop with strong market demand and relatively simple cultivation requirements, making it an attractive option for local farmers transitioning from traditional field crops. Furthermore, coffee requires shade for optimal growth, making it suitable for integration with existing tree stands. Agroforestry systems incorporating coffee under shade trees have been reported to yield higher production, improved bean quality, and enhanced

flavor compared with monoculture systems (Bote & Struik, 2011; Jácome et al., 2020).

The annual yield from coffee-based agroforestry systems is expected to enhance household income for the Selobanteng Village community. This increase in income could reduce the tendency for premature harvesting of teak and gmelina trees. Beyond the economic benefits, integrating coffee into agroforestry systems is projected to offer substantial ecological advantages, including reducing surface runoff (Van Noordwijk et al., 2004), controlling soil erosion, enhancing groundwater recharge, improving soil fertility, maintaining carbon reserves (Jácome et al., 2020), supporting water cycle regulation, and promoting biodiversity conservation (Méndez & Bacon, 2007). Such systems may also reduce pest and disease outbreaks (Supriadi & Pranowo, 2015) and provide habitats for diverse microfauna and macrofauna (O'Connor, Rahayu & Van Noordwijk, 2005; Mardiani et al., 2022; Fernandes et al., 2025).

The successful cultivation of coffee and the production of high-quality beans depend on both land characteristics and management practices. Optimal yields can be achieved only when coffee is grown under conditions matching its ecological requirements and on land classified as suitable for cultivation (Pascawijaya, Darsiharjo & Jupri, 2015; Hartono et al., 2018; Marbun et al., 2023). To support coffee development

in the Selobanteng community forest, a comprehensive land suitability evaluation is crucial. Land evaluation is a systematic process for assessing the capacity of land resources, resulting in classifications of actual and potential suitability. These classifications provide critical guidance for land use planning, estimation of productivity potential, and appropriate management decisions (Djaenudin et al., 2011).

This study evaluated the actual and potential suitability of land in the Selobanteng community forest for cultivating Arabica (*Coffea arabica* L.) and Robusta (*Coffea canephora* Pierre ex A.Froehner) using GIS-based spatial analysis (Yulistyarini, Fiqa & Laksono, 2008) and the agroecological matching method described by Djaenudin et al. (2011). It also proposed recommendations to address key limiting factors and strategies to enhance agricultural performance while improving the socioeconomic benefits of coffee production. By integrating field data with spatial analysis, the findings contribute to both scientific understanding and practical application of land suitability assessment for coffee in dry lowland community forests, offering a model for regions with similar climatic and resource constraints. These insights are intended to inform stakeholders and policymakers in promoting sustainable land use and rural development.

2 MATERIAL AND METHODS

2.1 Location and Time of Research

This research adopts a qualitative case study approach to assess land suitability for coffee agroforestry development in the community forest of Selobanteng Village, Situbondo, East Java. The case study method was selected because it allows an in-depth analysis of land suitability within its real ecological and management context, providing a comprehensive understanding of site-specific constraints and opportunities (Yin, 2018; Creswell & Poth, 2018). This study represents a

descriptive case study, as it aims to systematically describe biophysical land characteristics and their suitability for coffee cultivation, while also offering an exploratory component by identifying key limiting factors and potential management interventions (Djaenudin et al., 2011).

Field surveys were conducted in September 2019 to collect primary data on land characteristics relevant to coffee suitability. The survey focused on a reference area near a spring and included both existing coffee plantations on community-managed land and nearby potential planting sites. Data collection combined direct field observations, soil sampling, and measurements of topography, climate, and vegetation cover, supported by spatial data derived from GIS analysis.

Four distinct land uses system (LUS) types were selected as sampling units to represent the diversity of biophysical conditions within the community forest. These included teak stands (1), gmelina stands (2), mixed teak-gmelina stands (3), and mixed gardens (4). These LUSs, situated at varying altitudes, were chosen to represent the range of biophysical conditions within the community forest. Coffee cultivation is planned across all four LUSs, each located within designated forest blocks of Selobanteng Village (Table 1 and Figure 1). This combination of field-based and spatial data enabled a detailed evaluation of actual and potential land suitability within the case study area.

2.2 Equipment, Materials, and Data Sources

The field equipment used in this study included a GPS device (Garmin eTrex 32x, USA) to mark sampling locations, a camera (Canon EOS 6D, Japan) for documentation, a soil pH and humidity tester (Takemura DM-5, Japan) to measure soil pH and moisture levels, a clinometer (Suunto PM-5/360, Finland) to determine slope, a thermo-hygrometer (HTC-1, China) to record air temperature and humidity, and a lux meter (Extech LT40, USA) to measure light intensity. In addition, a soil sampling kit (Krisbow, Indonesia) consisting of a soil ring,

Table 1: Sampling points of the Selobanteng Village community forest area based on LUS.

No.	LUS	Altitude (masl)	Slope (%)	Forest block	Sampling point
1	Teak and gmelina	200–240	8–16	Sumber Sumber, Tegal Timur	SB3, SB4, SB27
2	Teak and gmelina	250	16–30	Pelalangan	SB28, SB29
3	Teak and gmelina	300	16–30	Rongkorong	SB9, SB10
4	Gmelina	270–280	8–16	Secangan, Bindung	SB25, SB34
5	Gmelina	422	8–16	Sumber Jrenguh	SB16
6	Teak	240	8–16	Tegal Timur	SB26
7	Teak	375	8–16	Bindung	SB35
8	Mixed garden	250–290	8–16	Sumber Sumber, Sumber Nyambuluh	SB7, SB13
9	Mixed garden	300–350	8–16	Sumber Sumber, Sumber Pagut, Sumber Kedawung	SB8, SB14, SB15, SB19
10	Mixed garden	425	8–16	Sumber Jrenguh	SB17

auger (drill), and hammer, also a scale (VKTECH SF-400, China) was used for collecting and measuring soil samples.

Digital resources comprised digital landform maps (RBI map) and digital topographic and LUS maps for Situbondo, obtained from the Geospatial Information Agency of the Republic of Indonesia (BIG RI). Climate data, including rainfall, temperature, and humidity averages for a five-year period (2014–2018), were obtained from the Meteorology, Climatology, and Geophysics Agency of the Republic of Indonesia (BMKG RI), specifically from the nearest climatic station—Lobawang/Dam Curah Suri station in Banyuglugur, Situbondo.

2.3 Land Survey and Soil Analysis

Land surveys were conducted to directly observe and measure land characteristics at designated sampling points corresponding to the identified LUSs (Table 1). Observations included both environmental conditions and soil collection. Soil samples were collected from each LUS, with three replicates taken at each sampling point, and analyzed at the Soil Science Laboratory, Faculty of Agriculture, University of Brawijaya, Malang.

The soil chemical properties tested included bulk density (g cm^{-3}), pH, organic carbon content (%), total nitrogen (%), carbon-to-nitrogen (C/N) ratio, organic matter content (%), available phosphorus (P_2O_5 , ppm), exchangeable potassium (K, me 100 g^{-1}), and cation exchange capacity (CEC, me 100 g^{-1}). Physical soil characteristics were determined by measuring the proportions of sand, silt, and clay to classify soil texture.

2.4 Development of GIS-Based Coffee Land Suitability Map

Data collection and integration were conducted using a combination of field survey data and secondary spatial

datasets. Field observations were collected from each LUS, while secondary data included altitude, temperature, slope, and LUS maps of Selobanteng Village. The LUS map served as the primary spatial reference. Tabular land suitability evaluation results were converted into spatial format through map digitization using ArcView 3.1 software, enabling integration of field-based information with spatial layers (Yulistyarini, Fiqi & Laksono, 2008). All datasets were standardized to a uniform coordinate system and spatial resolution prior to analysis.

Data analysis was performed using a GIS-based spatial overlay approach (QGIS 3.10 LTR). Environmental parameters, including altitude, temperature, and slope, were overlaid and matched with the agroecological requirements for coffee cultivation as defined by Djaenudin et al. (2011). Each parameter was evaluated to determine land suitability classes, allowing identification of areas with varying levels of actual and potential suitability for coffee cultivation across different LUS.

Visualization was carried out by generating a coffee land suitability map that displays the spatial distribution of suitability classes throughout Selobanteng Village. The final map visually represents areas classified as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), or unsuitable (N) for coffee cultivation. This visualization facilitates interpretation of spatial patterns and supports land use planning and decision-making for coffee agroforestry development.

2.5 Coffee Land Suitability Evaluation and Classification

Land suitability evaluation was conducted using the matching method by systematically comparing measured land characteristics with the ecological and agronomic requirements for coffee plant growth as defined by Djaenudin

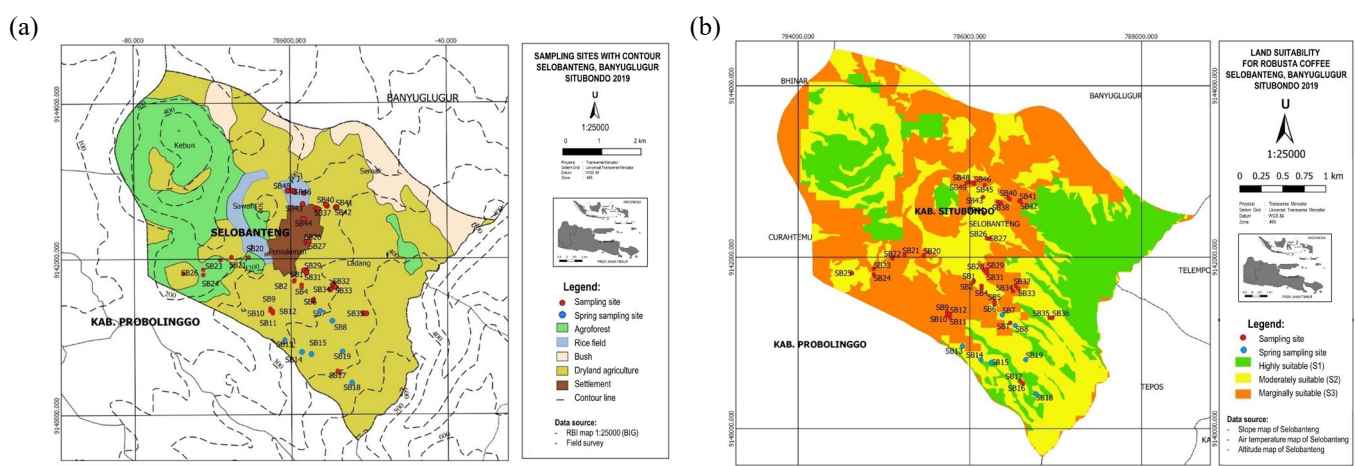


Figure 1: Map of Selobanteng showing (A) sampling sites overlaid with contour lines and (B) Robusta coffee land suitability based on GIS analysis.

et al. (2011). The evaluated land characteristics included water availability (wa), temperature (tc), rooting medium (rc), oxygen availability (oa), nutrient retention (nr), and erosion hazard (eh). Each characteristic was assessed against its corresponding reference threshold or suitability criterion to determine its level of adequacy for coffee cultivation. For example, soil organic matter content, as one of the indicators of nutrient retention, was compared with standard threshold values to determine whether it met the minimum requirement for optimal coffee growth. The overall land suitability was then determined based on the most limiting factor.

This evaluation produced two types of land suitability classifications: actual and potential. Actual suitability reflects the present condition of the land without intervention, while potential suitability considers improvements achievable through specific management practices. The suitability was conducted at the class (S1, S2, S3, N) and sub-class levels (wa, tc, rc, oa, nr, eh), where sub-classes indicate the dominant limiting factors identified during the matching process. When one or more land characteristics failed to meet optimal requirements, the corresponding constraint was assigned as a sub-class code. For example, S2-wa indicates moderate suitability limited by water availability, while S3-nr denotes marginal suitability constrained by nutrient retention. These classifications provide a framework for identifying appropriate management strategies to mitigate limiting factors and optimize coffee cultivation in the study area.

3 RESULTS

3.1 Coffee Land Suitability Based on GIS

The contour map of Selobanteng (Figure 1A), supported by field survey data (Table 1), shows that the area lies between 200 and 450 masl. This altitude range is unsuitable (N) for Arabica coffee based on GIS analysis but falls within the optimal range for Robusta coffee, which thrives at 100–500 masl. Accordingly, the land in Selobanteng is classified as highly suitable (S1), moderately suitable (S2), or marginally suitable (S3) for Robusta coffee cultivation, depending on local site conditions. Notably, no areas were categorized as not suitable (N) for Robusta coffee (Figure 1). The distribution of land suitability across these three classes is presented in Table 2. The S1 and S2 classes occupy relatively large and nearly equal portions of the area, indicating substantial potential for coffee cultivation. In contrast, land classified as S3 covers a smaller area, suggesting limited but feasible cultivation under specific management conditions.

Further analysis of the overlay map (Figure 1B) reveals that the most suitable areas for Robusta coffee cultivation are

concentrated in the southeastern part of Selobanteng Village. This region benefits from proximity to several natural springs, such as Sumber Sumber, Sumber Nyambuluh, Sumber Pagut, Sumber Kedawung, and Sumber Jrenguh. These water sources, represented by seven geotagged points, contribute significantly to classifying the surrounding land as highly suitable (S1) or moderately suitable (S2). In addition to the southeast, smaller patches of suitable land (S1 and S2) are also observed in the eastern and western parts of the village. However, these areas lie within Perhutani-managed forest land rather than community-managed forest, placing them outside the current framework for community-based Robusta coffee cultivation initiatives.

Table 2: Robusta coffee land suitability in Selobanteng community forest based on GIS.

Land suitability class	Area (ha)	Percentage (%)
Highly suitable (S1)	438.5	37.6
Moderately suitable (S2)	436.8	37.5
Marginally suitable (S3)	290.4	24.9
Not suitable (N)	0	0
Total	1165.8	100

Source: Land suitability criteria are based on the guidelines of Djaenudin et al. (2011).

3.2 Robusta Coffee Land Suitability Based on Integrated Land Characteristics

The results of the actual land suitability analysis for Robusta coffee cultivation in the community forest of Selobanteng, based on an integrated evaluation of several land characteristics including rainfall, duration of dry months, altitude, slope, air temperature, and soil physical and chemical properties, indicated that all LUSs were classified as not suitable (N), with the primary limiting factor being the extended dry period, and to a lesser extent, nutrient retention and erosion hazard. However, if this limiting factor can be mitigated, the potential land suitability is reclassified as marginally suitable (S3). Detailed results of this evaluation are presented in Table 3.

Furthermore, the rainfall pattern from 2014 to 2019 (Figure 2) indicates a pronounced seasonal regime, with precipitation concentrated in a short wet season and a prolonged dry period lasting approximately 5–9 months each year. During this extended dry season, monthly rainfall is consistently low and often near zero, indicating insufficient water availability to support coffee agroforestry without additional management interventions. This rainfall distribution highlights water availability as a major limiting factor for sustainable coffee cultivation in the Selobanteng community forest.

Table 3: Robusta coffee land suitability in Selobanteng community forest across LUS.

Land requirements/ characteristics	Land use system and land suitability class									
	T&G LUS 1	T&G LUS 2	T&G LUS 3	G LUS 4	G LUS 5	T LUS 6	T LUS 7	MG LUS 8	MG LUS 9	MG LUS 10
Assessment category	value	class	value	class	value	class	value	class	value	class
Water availability (wa)										
Ann rainfall (mm)	1238	S3	1238	S3	1238	S3	1238	S3	1238	S3
Dry month	5-9	N	5-9	N	5-9	N	5-9	N	5-9	N
Temperature (tc)										
Soil temp (oC)	27.9	S1	27.9	S1	27.9	S1	27.9	S1	27.9	S1
Altitude (m asl)	200-240	S2	250	S2	300	S1	270-280	S2	422	S1
Rooting medium (rc)										
Soil texture	L, SCL, SiCL	S1	C	S2	SiC	S1	SiL	S1	SiL	S1
Oxygen availability (oa)										
Drainage	Good	S1	Good	S1	Good	S1	Good	S1	Good	S1
Nutrient retention (0–30 cm) (nr)										
pH	5.4	S2	6.3	S2	5.0	S2	6.1	S2	6.3	S2
Org C (%)	0.1	N	1.9	S2	0.7	S3	1.4	S2	1.5	S2
CEC (me/100 g)	20.4	S1	23.5	S1	17.6	S1	19.0	S1	23.3	S1
N (%)	0.14	S2	0.22	S1	0.13	S2	0.17	S2	0.19	S2
P205 (ppm)	45.7	S1	67.6	S1	19.9	S1	14.0	S2	50.5	S1
K (mg/100 g)	0.8	S1	1.0	S1	0.4	S1	0.9	S1	1.2	S1
Erosion hazard (eh)										
Slope (%)	8-16	S2	16-30	S3	16-30	S3	8-16	S2	8-16	S2
Suitability class										
Actual	N	N	N	N	N	N	N	N	N	N
Potential	N	S3	S3	S3	S3	S3	S3	S3	S3	S3
Suitability subclass	N-nr	S3-wa, S3-eh	S3-wa, S3-eh	S3-wa	S3-wa	S3-wa	S3-wa	S3-wa	S3-wa	S3-wa

Notes: LUS: T = Teak; G = Gmelina, MG = Mixed garden; Soil texture: L = Loam, SCL = Sandy Clay Loam, SiCL = Silty Clay Loam, C = Clay, SiC = Silty Clay, SiL = Silty Loam; Class criteria: S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable.

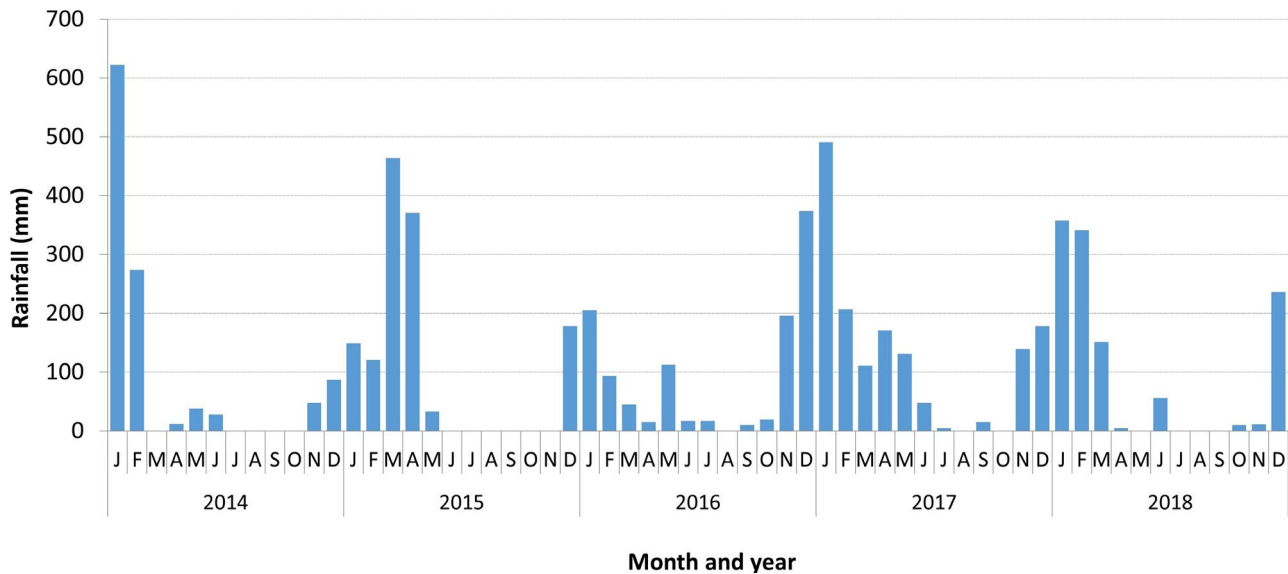


Figure 2: Monthly rainfall in Selobanteng (2014–2018) (Data source: BMKG RI).

4 DISCUSSIONS

4.1 Coffee Land Suitability and Mitigation of Limiting Factors

Based on GIS analysis, the community forest area in Selobanteng Village, situated at an altitude of 200–450 m above sea level, falls within the highly suitable (S1), moderately suitable (S2), and marginally suitable (S3) classes for Robusta coffee. In contrast, the area is unsuitable for Arabica coffee cultivation. *Arabica* and *Robusta* coffee are two economically important species that generally share similar land characteristics but differ markedly in their altitude preferences. Altitude is a crucial factor determining land suitability for coffee cultivation. Arabica grows best at higher elevations, between 650 and 1500 m above sea level, while Robusta performs better at lower altitudes, ranging from 0 to 700 m (Ahmed et al., 2021; Mihai et al., 2024). Consequently, their temperature requirements differ: Arabica thrives at 15–25 °C, whereas Robusta prefers 21–24 °C (Campuzano-Duque et al., 2021). Therefore, subsequent analyses focus on Robusta coffee, as it is the only species suitable for cultivation in the study site.

The matching method indicated that all areas within the Selobanteng community forest are currently classified as not suitable (N) for Robusta coffee, primarily due to inadequate water availability caused by prolonged dry months. However, if this constraint is addressed, the land can potentially be upgraded to at least marginally suitable (S3) or moderately suitable (S2). Water deficiency severely affects plant growth and productivity, particularly in coffee, which requires consistent moisture during flowering and fruiting stages (Najiyati & Danarti, 2001; Parada-Molina et al., 2025).

Therefore, any coffee development program in the Selobanteng community forest must prioritize land management strategies that enhance water availability. Additional constraints, such as limited nutrient retention and erosion hazards, were also identified. Implementing appropriate management practices can alleviate these limitations and improve land suitability for coffee cultivation in the Selobanteng community forest.

Selecting appropriate coffee varieties and high-quality seedlings is crucial for ensuring strong survival rates and the successful establishment of plantations. Ideally, seedlings should be about seven months old and meet several standards, including vigorous growth, freedom from pests and diseases, uniform morphology, known provenance, tolerance to environmental stress, and a well-developed root system (Breitler et al., 2022). These requirements align with the technical standards outlined in the Ministry of Agriculture Regulation of the Republic of Indonesia No. 49/Permentan/OT.140/4/2014 on Good Agricultural Practices (GAP) for coffee in Indonesia. To enhance productivity in dryland areas, the use of drought-tolerant coffee varieties is recommended. A promising approach involves using grafted seedlings that combine Robusta rootstocks with Arabica scions, known as Robbica. Robusta rootstocks offer strong root development and drought and nematode resistance, while Arabica scions contribute superior bean quality, lower caffeine content, and distinct flavor profiles (Bertrand, Etienne & Eskes, 2001; Evizal et al., 2018; Campuzano-Duque et al., 2021). Research by Alnopri and Hermawan (2015) demonstrated that Robbica coffee, produced by grafting Arabica cultivars such as S-1934, Kartika, Sigarutang, and Andung Sari onto Robusta rootstocks, thrived in lowland Bengkulu, Sumatra, under legume shade trees. These grafted varieties

outperformed Arabica in growth, physiology, and yield under comparable conditions. The optimal planting spacing for Robusta coffee was determined to be 2 m × 2.5 m.

Water remains the principal limiting factor for coffee cultivation in the Selobanteng community forest due to extended dry months, emphasizing the need for irrigation investment. Potential measures include utilizing nearby springs such as those in Sumber Kedawung, constructing piped systems, installing sprinklers, creating rainwater ponds, and digging small pits beside each plant to collect and store water. A simple rainwater pond can be made by excavating a one-square-meter hole, lining it with plastic, and using cloth wicks for slow-release irrigation (Iijima et al., 2016). Basic drip irrigation using plastic bottles can also support young coffee plants during severe dry periods (Tadesse, Tesfaye & Abera, 2020). Additional moisture conservation techniques include mulching with dry leaves. Field surveys confirm the practicality of these measures. An eight-year-old coffee plantation in Sumber Kedawung, cultivated under shade trees, maintained with organic mulch, and equipped with water pits beside the plants (Figure 3), exemplifies successful coffee agroforestry and water-efficient farming practices that can be replicated across other suitable sites in Selobanteng Village.

Soil physical and chemical properties generally support Robusta coffee cultivation in the Selobanteng community forest. Low soil bulk density indicates good drainage and aeration, while soil textures are mostly sandy loam to clayey loam, providing favorable rooting conditions, except in clay-dominated sites that restrict root penetration (Nita et al., 2014; Rizal et al., 2022). Soil pH values largely fall within or close

to the optimal range for Robusta coffee. In contrast, soil organic matter shows considerable variation and represents the main soil-related constraint, as very low C-organic content reduces nutrient retention and leads to marginal or not suitable classifications in some LUSs (Rahmah, Yusra & Uma, 2014). Meanwhile, phosphorus, potassium, and cation exchange capacity are consistently high across sites, indicating generally adequate nutrient availability (Yamani, 2012).

Therefore, the addition of organic matter, particularly through manure and compost, is essential in LUS 1 areas, specifically the Sumber Sumber and Tegal Timur blocks (teak and gmelina stands), where the soil organic carbon content is extremely low at only 0.1%. For optimal growth, coffee plants require soil organic carbon levels between 2% and 5%. Incorporating organic matter enhances soil fertility and improves its structure, creating a crumbly texture that facilitates water infiltration and increases water-holding capacity (Mendonça et al., 2018). This is particularly important because more than 90% of coffee root biomass is concentrated within the top 0–30 cm of soil, making the crop highly sensitive to soil structure and oxygen availability. Well-aerated, friable soil supports healthy root development by ensuring sufficient oxygen and water supply, whereas compacted or waterlogged conditions can restrict root growth and reduce plant performance (Najiyati & Danarti, 2001; Francisco et al., 2022; Parada-Molina et al., 2025).

To address the issue of steep slopes and minimize soil erosion, understorey plants can be used as ground cover to protect the soil from the direct impact of rainfall. Vegetation covers may include grasses, shrubs, small trees, or leguminous

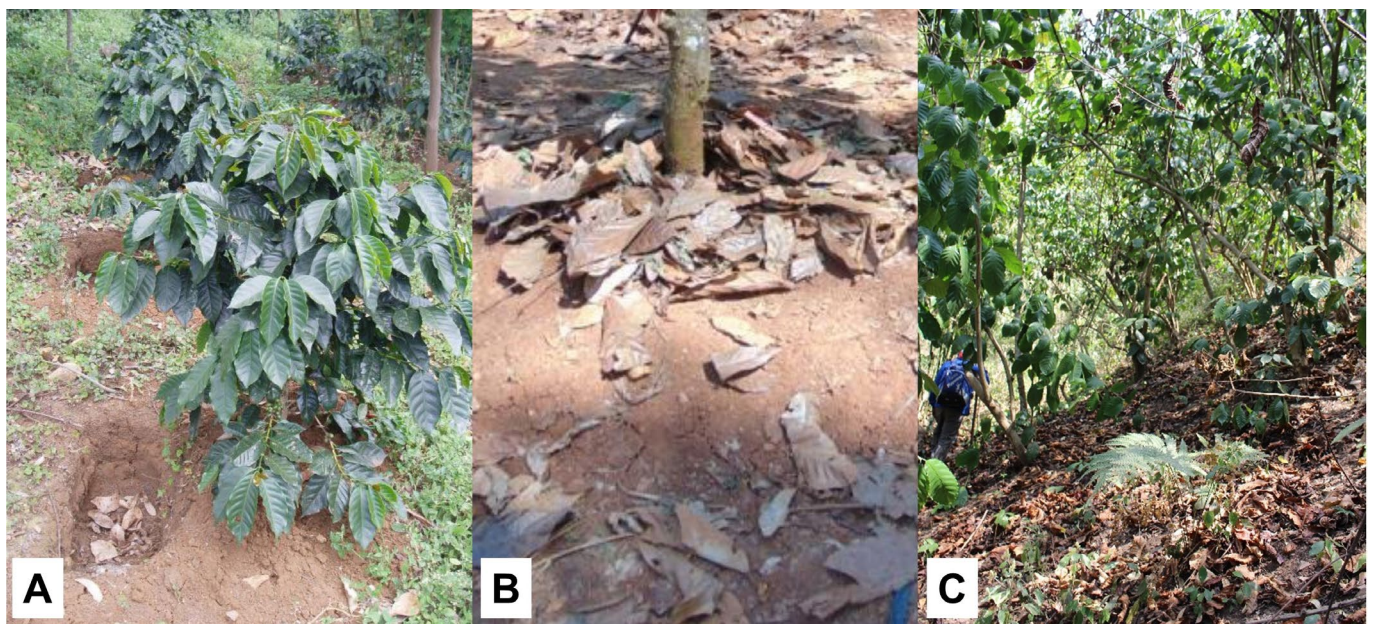


Figure 3: Soil and vegetation management practices in coffee cultivation: (A) Rainwater pit beside a coffee plant; (B) Leaf litter mulch around the base of a coffee plant; (C) Eight-year-old coffee agroforestry in Sumber Kedawung with leaf litter mulch beneath the canopy.

cover crops (Zuazo & Pleguezuelo, 2008; Stagnari et al., 2017). Partial weeding—removing vegetation only within a one-meter radius beneath the coffee tree canopy—can be strategically applied on sloped terrain to protect young coffee plants. This approach not only conserves soil on hilly or sloping lands and reduces erosion to tolerable levels (Iijima et al., 2003) but also maintains some vegetative cover, which supports soil structure and moisture retention. The effectiveness of partial weeding is influenced by the slope of the terrain, as steeper areas (16–30%) experience higher runoff and erosion risk, requiring careful management (Blanco-Sepúlveda, Aguilar-Carrillo & Lima 2021). Additionally, the form and arrangement of planting, such as contour or row alignment along the slope, can further enhance soil conservation and water distribution (Raj, Borah & Chettri, 2025). Physical characteristics of the soil, particularly texture, also affect the suitability for coffee cultivation, as soils with better structure and infiltration rates can better withstand reduced vegetative cover (Parwito et al., 2024). In the Selobanteng community forest, slope-based land suitability analysis indicates that most areas are S2 (moderately suitable), while two LUSs in Pelalangan and Rongkorong are S3 (marginally suitable) due to steeper slopes and potentially more challenging soil conditions.

In terms of long-term land management, the coffee-based agroforestry system provides a sustainable model for cultivation in the Selobanteng community forest. This approach integrates coffee plants with leguminous species, fruit-bearing trees, or other multipurpose plants that serve as shade or protective species. Consequently, a multistrata vegetation structure is formed, resembling the ecological complexity of a natural forest. This system not only enhances biodiversity and ecological resilience but also supports microclimate regulation, nutrient cycling, and improved soil stability, all of which are vital for sustainable coffee production (Budidarsono & Wijaya, 2004; Carmo et al., 2014; Jácome et al., 2020).

4.2 Development of Coffee-Based Agroforestry System

Agroforestry-based coffee cultivation is recommended in the Selobanteng community forest due to its ecological and agronomic advantages. The multistrata canopy structure reduces soil erosion, regulates the microclimate by filtering sunlight, and maintains humidity around coffee plants (Nasiro et al., 2024). Shade trees enhance soil fertility through litter inputs that increase soil organic matter for coffee growth (Misgana et al., 2024). However, coffee productivity depends on shade regulation, as moderate shade levels up to about 30–40% generally do not reduce yield, whereas excessive shading can limit photosynthesis and decrease production (Elevitch et al., 2009; Bote & Struik, 2011). Agroforestry systems also improve water management by increasing rainfall interception,

reducing surface runoff, enhancing infiltration, and improving soil moisture retention (Jose, 2009). Deep-rooted trees enhance soil porosity and indirectly support soil fauna through organic matter contributions, which is particularly beneficial on sloped terrain (O'Connor, Rahayu & Van Noordwijk, 2005; Mardiani et al., 2022; Fernandes et al., 2025).

Litter from shade trees suppresses weed growth and supplies nutrients such as nitrogen. For instance, litter from cempaka (*Magnolia champaca* (L.) Baill. ex Pierre) contributes up to 66 kg ha⁻¹ of nitrogen, gamal (*Gliricidia sepium* (Jacq.) Kunth) about 61 kg ha⁻¹, and dadap (*Erythrina subumbrans* (Hassk.) Merr.) up to 120 kg ha⁻¹. Lamtoro (*Leucaena leucocephala* (Lam.) de Wit) effectively increases soil organic matter, while timber species such as teak, sengon (*Falcataria falcata* (L.) Greuter & R. Rankin), mindi (*Melia azedarach* L.), and mountain waru (*Hibiscus macrophyllus* Roxb. ex Hornem.) improve soil mineral nutrient availability (Saragih, 2017). Ideal shade trees should possess non-competitive root systems, tolerate pruning, form crowns rapidly, and remain resistant to pests and diseases. Additional desirable traits include tall growth, small leaves that allow filtered light, sturdy branching, and minimal leaf shedding during the dry season to maintain soil cover (Purnamasari et al., 2022).

Table 4 presents recommended shade tree species for coffee agroforestry development in lowland areas, highlighting their multifunctional roles in both production and ecosystem services. The selected species comprise a diverse range of families, with Fabaceae being dominant, reflecting their importance in agroforestry systems due to rapid growth, nitrogen fixation, and contributions to soil fertility (De Oliveira et al., 2015). Many species, such as gamal, kaliandra, dadap, and lamtoro, provide effective shade while also supplying firewood, fodder, green manure, and erosion control. Several fruit-producing trees, including jackfruit, durian, avocado, stink bean and dogfruit, offer additional income and food sources for farmers, thereby enhancing livelihood resilience. Timber-oriented species such as sengon, suren, and umbrella tree contribute long-term economic value and structural canopy cover. Overall, the combination of shade, soil improvement, erosion control, and diverse economic outputs supports the suitability of these species for sustainable coffee agroforestry systems in lowland environments (Danarto, Budiharta & Fauziah, 2019; Danarto & Yulistyarini, 2019). Furthermore, in the relatively dry, lowland Selobanteng community forest, simplified agroforestry systems with fewer than five shade tree species are recommended to minimize water competition. Shade trees increase evapotranspiration and absorb water that would otherwise be available to coffee plants; therefore, careful species selection and density regulation are essential (Jose, 2009; Vaast & Somarriba, 2014).

Table 4: Recommended shade tree species for coffee agroforestry in lowland areas.

No.	Scientific name	Local name	Family	Potential uses
1	<i>Azadirachta indica</i> A.Juss.	mimba, neem, indian lilac	Meliaceae	Firewood, cabinet wood, medicinal uses, biopesticide, leaves for animal feed
2	<i>Falcataria falcata</i> (L.) Greuter & R.Rankin	segon, moluccan albizia, silk tree	Fabaceae (Leguminosae)	Fast-growing building wood, light construction, pulp, leaves for animal feed
3	<i>Artocarpus heterophyllus</i> Lam.	nangka, jackfruit	Moraceae	Edible fruit, timber (furniture, construction), fodder
4	<i>Calliandra calothyrsus</i> Meisn.	kaliandra, red calliandra	Fabaceae (Leguminosae)	Firewood, green manure, erosion control, bee forage, leaves for animal feed
5	<i>Durio zibethinus</i> L.	Durian	Malvaceae (Bombacaceae)	Edible fruit, timber (light construction), cultural/economic value
6	<i>Erythrina subumbrans</i> (Hassk.) Merr.	dadap, coral tree	Fabaceae (Leguminosae)	Shade tree, boundary marker, soil enrichment (N-fixing), boat material
7	<i>Gliricidia sepium</i> (Jacq.) Kunth	gamal, gliricidia, madre de cacao	Fabaceae (Leguminosae)	Firewood, live fence, green manure, erosion control, leaves for animal feed
8	<i>Leucaena leucocephala</i> (Lam.) de Wit	lamtoro, river tamarind, white leadtree	Fabaceae (Leguminosae)	Firewood, timber, erosion control, fodder, fruit (young pods edible)
9	<i>Maesopsis eminii</i> Engl.	kayu afrika, umbrella tree, musizi	Rhamnaceae	Timber (construction, furniture), firewood, shade tree (coffee/cocoa)
10	<i>Parkia speciosa</i> Hassk.	pete, stink bean, bitter bean	Fabaceae (Leguminosae)	Edible fruit (pods), source of organic matter, agroforestry species
11	<i>Persea Americana</i> Mill.	alpukat, avocado	Lauraceae	Edible fruit, oil extraction, medicinal uses, leaves for animal feed
12	<i>Archidendron pauciflorum</i> (Benth.) I.C.Nielsen	jengkol, dogfruit, jering	Fabaceae (Leguminosae)	Edible fruit, traditional medicine, source of organic matter
13	<i>Toona sureni</i> (Blume) Merr.	suren, surian, toona	Meliaceae	High-quality timber (furniture, construction), reforestation, shade tree

The available land comprises LUSs dominated by teak, gmelina, their combination, and mixed gardens. Teak and gmelina are deciduous species that shed all their leaves during the dry season, exposing coffee plants to moisture stress (Sachan et al., 2020). This can be mitigated by inter planting evergreen legumes such as lamtoro, which retains its leaves, fixes atmospheric nitrogen, and provides valuable fodder (Tomic et al., 2023). Field surveys also identified sengan plantations in Sumber Nyambuluh, currently used as demonstration plots and classified as suitable for coffee cultivation. Among all land types, mixed gardens are considered the most favorable due to their multistrata vegetation, proximity to springs, and moderately fertile soils (C-organic class S2). However, their elevation and distance from settlements increase labor and maintenance costs. In contrast, coffee plots located near residential areas benefit from easier access to water and lower maintenance requirements, thereby improving the overall success of cultivation efforts.

5 CONCLUSIONS

Arabica coffee was not suitable (N) for cultivation in the Selobanteng community forest because of altitude limitations,

while Robusta coffee was also classified as not suitable (N) due to water scarcity, low organic matter, and steep slopes. Land suitability could be improved to marginally suitable (S3) or moderately suitable (S2) through drought-tolerant varieties, irrigation and water conservation, organic matter application, erosion control, and agroforestry practices with limited shade-tree species.

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7 AUTHOR CONTRIBUTIONS

Conceptual Idea: Hapsari, L.; Yulistyarini, T., Methodology design: Hapsari, L.; Yulistyarini, T.; Laksono, R.A.; Data collection: Hapsari, L.; Trimanto, T.; Danarto, S.A.; Mas'udah, S.; Damaiyani, J.; Laksono, R.A.; Budiharta,

S.; Yulistyarini, T., Data analysis and interpretation: Hapsari, L.; Yulistyarini, T.; Laksono, R.A., and Writing and editing: Hapsari, L.; Yulistyarini, T.

8 DATA AVAILABILITY STATEMENT

Data available upon request to authors.

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