



LAND SUITABILITY FOR COFFEE AGROFORESTRIES DEVELOPMENT IN THE CILIWUNG HULU WATERSHED, WEST JAVA

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ABSTRACT

Assessing land suitability for coffee agroforestry in the Upper Ciliwung Watershed is crucial for efficient land resource management, increased coffee production, and sustainability. Currently, forest cover and natural vegetation, which facilitate water infiltration, account for only about 9.7% of the total watershed area. This study aimed to assess land suitability for coffee agroforestry in the Upper Ciliwung Watershed by matching crop requirements with land characteristics and identifying key limiting factors affecting sustainability. The land suitability analysis integrated crop growth requirements with land characteristics using a matching method to determine suitability for coffee cultivation. The analysis identified three research locations (Cibulao, Rawa Gede, and Cisuren) as marginally suitable (S3) and one location (Cikoneng) as moderately suitable (S2). Soil pH values were approximately 4.53 in Cibulao, 5.00 in Rawa Gede, 4.98 in Cikoneng, and 4.12 in Cisuren. At the same time, slope gradients ranged from about 8% to 15% in Cibulao and Cikoneng and from 16% to 25% in Rawa Gede and Cisuren. Low soil pH, steep slopes, and potential erosion hazard were identified as the main limiting factors for coffee agroforestry. If unmanaged, these constraints may limit productivity and threaten the long-term ecological functions of the watershed. To improve land suitability and ensure the sustainability of biophysical land conditions, recommended management practices include soil liming, constructing contour bunds, establishing vegetative terrace reinforcement, and building terraces.

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Introduction

The Upper Ciliwung Watershed, located in Bogor District, is the largest coffee-growing area in West Java Province. Coffee is one of the leading commodities in Bogor Regency because the climate and altitude are suitable for growing coffee in the Upper Ciliwung Watershed (Fitri *et al.*, 2024). Most coffee plants in West Java Province are dominated by community plantations covering approximately 584 ha in community settlements (Direktorat Jenderal Perkebunan, 2016; Maulana, 2022). In the Upper

Ciliwung Watershed, Perhutani (a State-owned Enterprise) plants coffee under agroforestry. Coffee is a crop suitable for upstream watershed conservation. Coffee plants need shade to thrive; therefore, forest stands provide appropriate shading conditions (Hidayat *et al.*, 2017). Implementing agroforestry crop production systems is an approach to optimise land use while maintaining ecological functions (Yulhendri *et al.*, 2020). Therefore, coffee agroforestry can integrate agricultural production with

watershed conservation functions, particularly in areas with steep slopes and high erosion risks. Coffee agroforestry systems must consider environmental conditions, including climate variability, that may affect coffee production (Tamaradewi *et al.*, 2019).

However, expanding and managing coffee agroforestry in upstream watershed areas requires careful evaluation of land characteristics to prevent land degradation and ensure long-term sustainability. Land suitability evaluation is essential for designing sustainable land-use and management systems (Ostovari *et al.*, 2019; Sadiq *et al.*, 2023). Research on land suitability evaluation, including assessments of specific crops, has been widely conducted to provide essential information for optimising agricultural productivity while maintaining environmental sustainability (Kome *et al.*, 2020; Tadesse & Negese, 2020). The purpose of land evaluation is to determine the potential or value of land based on its use, and to help establish the relationship between land conditions and land-use (Ritung *et al.*, 2007).

Although studies on land suitability for agroforestry are common, research specifically focusing on land suitability for coffee agroforestry remains limited, especially regarding site-specific biophysical constraints such as soil properties and potential erosion hazards. Existing studies are usually confined to a single village (Bangun *et al.*, 2022; Ariandi *et al.*, 2025) and do not consider soil chemical properties (Affan & Zayadi, 2024). Moreover, a watershed-based land suitability evaluation for coffee agroforestry in the Upper Ciliwung region has not yet been conducted. Consequently, the management of coffee agroforestry systems may not be fully aligned with the biophysical characteristics of upstream watershed areas. This gap may lead to suboptimal productivity and increased risk of soil degradation.

The evaluation of land suitability for coffee agroforestry in watersheds is necessary to assess the compatibility between existing land characteristics (physical, chemical, and climatic properties) and crop requirements. This

study aimed to assess land suitability for coffee agroforestry in the Upper Ciliwung Watershed by systematically matching crop requirements with land characteristics and identifying limiting factors to support sustainable land-use management. The findings are expected to serve as a reference for future land suitability evaluations and contribute to sustainable land-use practices and soil conservation efforts in the upstream areas of the Upper Ciliwung Watershed in West Java Province.

Material And Methods

This research was conducted in four areas of the Upper Ciliwung Watershed of West Java Province: Cibulao, Cikoneng, Rawa Gede, and Cisuren, from June to October 2024. These four areas were selected as the research sites because of the presence of coffee agroforestry in the Upper Ciliwung Watershed. Figure 1 presents a description of the characteristics of the four areas in the Upper Ciliwung Watershed where the research was conducted.

Data Collection

Data collection for this study was conducted in several stages, including determining research objects, conducting a literature review to obtain preliminary information about the study area, and preparing research tools and materials such as administrative maps and other necessary datasets. A land unit map was generated by overlaying the topographic map (slope), soil map (soil type), land cover map (land-use), and watershed boundary map of the Upper Ciliwung Watershed. In addition, data on rainfall, temperature, slope gradient, potential erosion hazards, and general site conditions were collected. Physical condition data were obtained from the Citarum–Ciliwung Watershed Management Authority. Soil sampling was conducted at five points within a 50 m × 20 m plot, with sampling points located at four corners and one point at the centre of the plot. Soil samples were collected at depths of 0 to 30 cm and 30 to 60 cm using a hoe and soil auger. The collected samples were composited

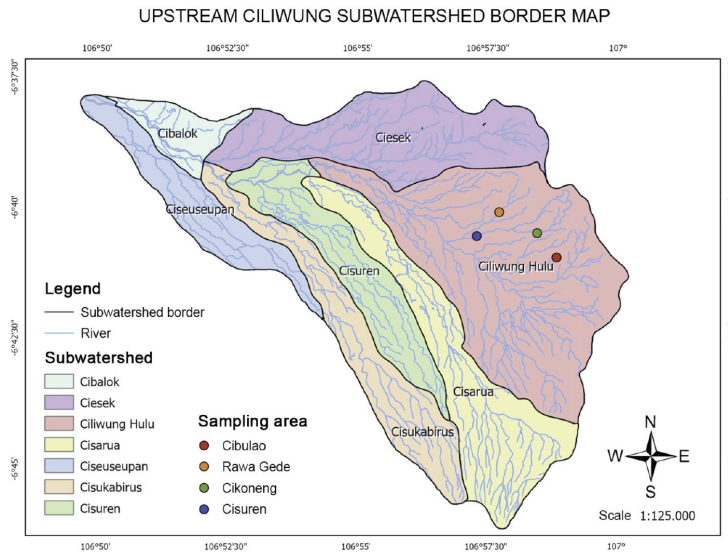


Figure 1: Map of the research locations
Source: BPDASHL (2024) modified by the authors

and stored in clear plastic bags for laboratory analysis. Composite soil samples were used to assess soil chemical properties (cation exchange capacity, pH, organic C, total N, available K, and available P_2O_5) and physical properties (soil texture). The sampling locations were purposively selected and situated in community-managed coffee agroforestry areas. All the maps were sourced from the Forest Area Consolidation Agency, Ministry of Environment and Forestry (Rahmawaty *et al.*, 2021). This study did not directly measure erosion hazards. The erosion risk was estimated using land slope as a topographic indicator, assuming that steeper slopes corresponded to a higher potential erosion risk. This approach is based on the general principle that steeper slopes facilitate faster water flow, increasing soil detachment and transport (Li *et al.*, 2020).

Data Analysis

Land mapping units were delineated by overlaying several land-related layers, including topographic, soil type, and land-use maps of the Upper Ciliwung Watershed. Figure 2 shows the topographic, soil, and land-cover maps. Analysis of the biophysical parameters of the

land units was performed using ArcGIS 10.8 software, which facilitates data input, storage, retrieval, processing, analysis, and geospatial visualisation. The resulting land-mapping units were categorised, as shown in Table 1.

The average rainfall data for the Upper Ciliwung Watershed from 2010 to 2019 were calculated using the Thiessen Polygon method based on the locations of the rainfall measurement stations in Microsoft Excel. Mathematically, the average rainfall obtained using the Thiessen Polygon method can be expressed as follows:

$$Px = \frac{A1P1 + \dots + AnPn}{\Sigma A} \quad (1)$$

Where:

Px = Average monthly rainfall (mm)

$A1-A_n$ = Area covered by each rainfall station (ha)

$P1-P_n$ = Monthly rainfall at each station (mm)

ΣA = Total area (ha)

The formula used to calculate the standard deviation of the rainfall data in the Upper Ciliwung Watershed from 2010 to 2019 is expressed as follows:

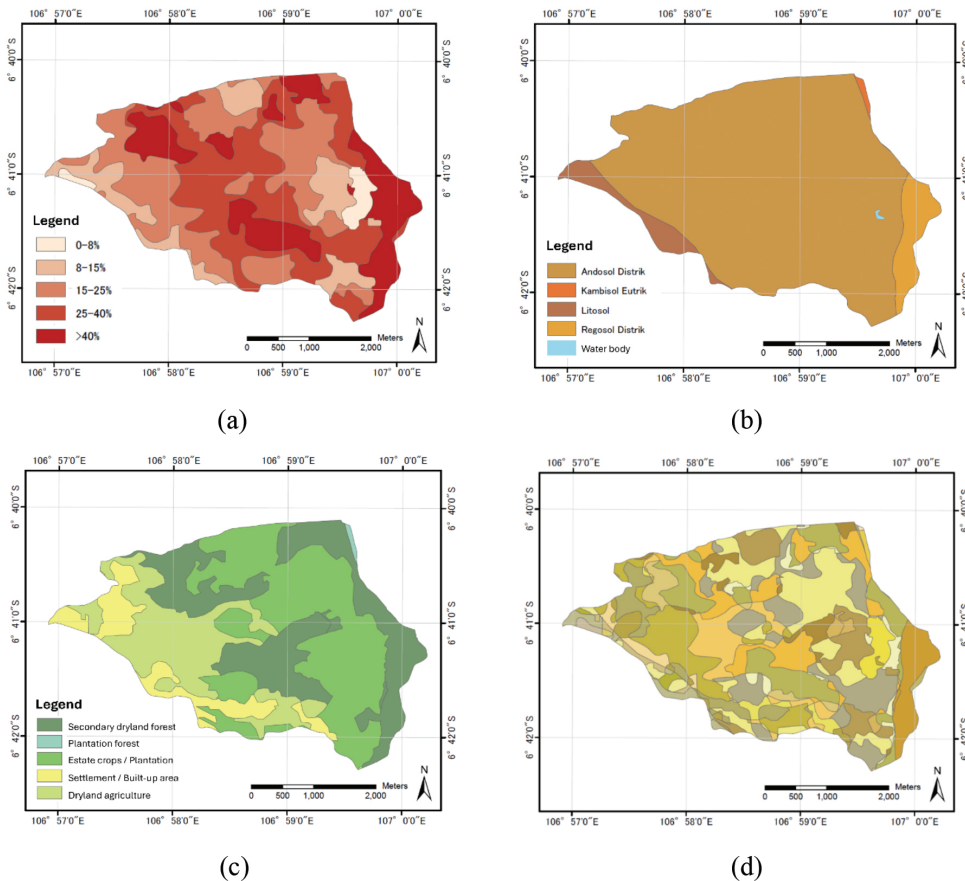


Figure 2: The maps of (a) topographic map, (b) soil map, and (c) land cover map overlaid to create (d) land unit map

Table 1: Land mapping unit characteristics

No	Land Unit	Soil Type	Slope (%)	Meters Above Sea Level	Area (ha)
1	Cibulao	Inceptisol	8–15	1,391	20
2	Rawa Gede	Inceptisol	8–15	1,407	5
3	Cikoneng	Inceptisol	16–25	1,396	5
4	Cisuren	Inceptisol	16–25	1,245	32

Standard deviation

$$Sd = \sqrt{\frac{\sum_{i=1}^n (Xi - \bar{X})^2}{n-1}} \quad (2)$$

Where:

Sd = Standard deviation of rainfall

$\bar{X}$ = Mean (average) rainfall value

Xi = Rainfall measurement value for the i-th observation

n = Number of rainfall data points

Soil samples were analysed in the laboratory to determine soil texture using the pipette method, soil Cation Exchange Capacity (CEC) using the NH_4OAc 1N pH 7 method, soil pH using the electrometric method, organic C using the Walkley and Black method, total N using the Kjeldahl method, and available K and available P_2O_5 using the Bray-1 method. Land suitability was analysed by matching land quality with

plant growth requirements according to the procedure. The four land suitability classes were highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and unsuitable (N). The procedure for determining land suitability for coffee agroforestry involved field surveys, analysis of biophysical parameters (climate, soil, and topography), and matching soil data with preferred coffee conditions based on Ritung *et al.* (2011).

Results and Discussion

Climate Criteria in the Upper Ciliwung Watershed

Climatic conditions influence land suitability for coffee agroforestry systems. Climate change is expected to reduce suitability for future coffee cultivation because changing climatic conditions have been shown to decrease land suitability for coffee production (Moreira *et al.*, 2020). Climate-related threats to coffee agroforestry include extreme temperatures and increasingly erratic rainfall patterns, which can reduce coffee yield (Bilen *et al.*, 2022). Furthermore, climate change is presumed to negatively affect coffee plant growth (Cheserek & Gichimu, 2012), reduce crop productivity, particularly for coffee (Iscaro, 2014), and increase the incidence of pests and diseases.

The climate characteristics of coffee agroforestry land in the Upper Ciliwung Watershed were used to assess suitability based on two parameters: Temperature and rainfall. Based on Citeko Station data, the annual average temperature in the Upper Ciliwung watershed ranges from 16.20°C to 26.80°C, with an average of 21.20°C. The highest air temperature of 26.8°C occurred in October, and the lowest was 16.2°C in August. Temperature differences at the research site are influenced by elevation, light intensity affecting the canopy, and environmental conditions. Air temperature at the earth's surface is influenced by light intensity; therefore, several plant species can

grow and adapt to this environment (Abdillah *et al.*, 2018; Rahmawaty *et al.*, 2023). Arabica coffee agroforestry grows well at 16°C to 20°C, while robusta coffee agroforestry will grow well at 20°C to 24°C (Ritung *et al.*, 2011).

The research location is approximately 1,450 m above sea level, resulting in relatively low to moderate temperatures. The altitude of a place affects the climate and temperature in an area; the higher the altitude, the lower the temperature in the area (Saputra & Lee, 2021). In addition to temperature, rainfall is an important factor in coffee agroforestry growth. Figure 3 shows rainfall data from the research locations. The average rainfall in the Upper Ciliwung Watershed area, which was 2,913 mm/year, was calculated using the Thiessen polygon method. This rainfall amount fell within the high-rainfall category. The rainfall for each observation station, namely Gunung Mas Station and Gadog Station, was about 3,518 mm/year, and the area covered by Depok Station was 3,065, 3,518, and 2,557 mm/year, respectively.

Current rainfall and temperature conditions in the Upper Ciliwung Watershed are suitable for coffee growth. The ideal microclimatic conditions for coffee include air temperatures of 15°C to 25°C (Balittri, 2017), while the optimal temperature range for Arabica coffee growth is 18°C to 21°C (Ehrenbergerová *et al.*, 2017), with annual rainfall of approximately 1,250 to 2,500 mm (Balittri, 2017). For Robusta coffee, optimal temperatures range from 21°C to 24°C, and the most favourable annual rainfall ranges between 2,000 and 3,000 mm (Djaenudin *et al.*, 2003). Adequate rainfall improves coffee plant growth by satisfying the water requirements. However, rainfall patterns also influence flowering and fruiting. High rainfall is associated with reduced productivity because it may cause coffee beans to become mouldy or defective (Kath *et al.*, 2021). Therefore, changes in rainfall patterns may lead to a yield decline, as both insufficient and excessive rainfall outside the optimal range can adversely affect coffee growth.

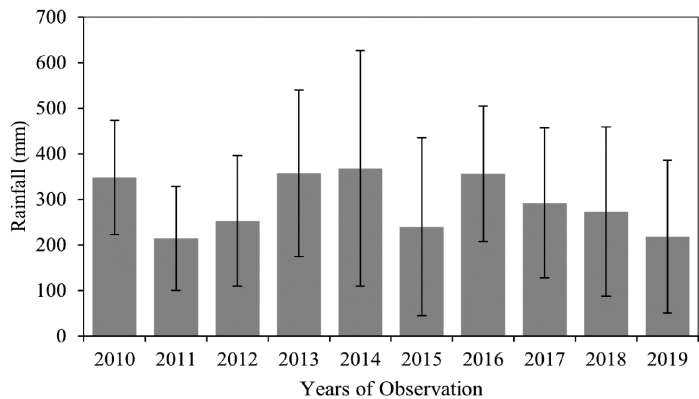


Figure 3: Rainfall data in the research location for 2010 to 2019

Soil Properties in the Upper Ciliwang Watershed

The soil properties of coffee agroforestry in the Upper Ciliwang Watershed include soil texture, cation exchange capacity, and soil pH, as shown in Table 2. Well-textured soils support plant growth (Fitri *et al.*, 2022; Masnang *et al.*, 2023). The soil texture at all research locations was classified as clayey loam, characterised by a slippery feel, somewhat attached, able to form firm balls, and able to form rolls that are easily destroyed (Mustawa *et al.*, 2017). Loam and clayey soils bind water better than sandy soils. In Table 1, the results of laboratory analysis show that on coffee agroforestry land in Cibulao the cation exchange capacity value is 36.02 me/100 g, followed by Cikoneng cation exchange capacity value of 25.45 me/100 g, Rawa Gede is the lowest Cation Exchange Capacity (CEC) value of 24.46 me/100 g while the highest cation exchange capacity value is 38.85 me/100 g in Cisuren. An increase in soil CEC was associated with a decrease in coffee

production and vice versa. Mukhlis *et al.* (2011) reported that a higher soil CEC reflects greater colloidal activity, which enhances the capacity of the soil to adsorb and exchange cations. Soils with high cation exchange capacity can absorb and supply nutrients better than soils with low cation exchange capacity. The elements are present in the soil sorption complex; therefore, nutrients are not easily lost or leached by water (Risaldi *et al.*, 2023).

The soil at all observation points was classified as acidic. Several factors may have influenced soil acidity in the study area. The research location was a highland area with high rainfall, which may enhance leaching processes (Prabowo *et al.*, 2018). However, canopy cover in agroforestry systems may reduce direct rainfall impact and surface runoff. Therefore, soil acidity in the study area cannot be attributed solely to leaching. Other potential contributing factors

Table 2: Measurement results of soil texture, cation exchange capacity and soil pH at the research site

Land Unit	Fraction (%)			Textural Class	Cation Exchange Capacity	Soil pH
	Sand	Dust	Clay			
Cibulao	24.33	42.27	28.76	Clay loam	36.02	4.53
Rawa Gede	35.85	45.86	12.75	Clay loam	25.45	5.00
Cikoneng	43.35	29.33	21.16	Clay loam	24.46	4.98
Cisuren	29.63	49.42	14.18	Clay loam	38.85	4.12

Source: Fitri *et al.* (2024)

may include parent material characteristics and the presence of H^+ (hydrogen) ions and Al^{3+} (aluminium) ions in the soil solution, which are associated with acidic soils in tropical environments (Sudomo & Ary, 2017). This study did not directly analyse exchangeable Al , H^+ saturation, or parent material characteristics. Further investigation is required to clarify the dominant mechanisms controlling soil acidity in the Upper Ciliwung Watershed.

The highest C-organic value in coffee agroforestry land was 17.33 in the Cisuren area, and the lowest in coffee agroforestry land was 6.00 in Cibulao (Table 3). Litter is the primary source of soil organic matter obtained through decomposition. After falling to the soil surface, litter undergoes physical fragmentation and biochemical decomposition by soil organisms and microorganisms, releasing soluble nutrients that contribute to plant nutrition. The availability of organic carbon in Cisuren agroforestry land is greater than that in Cibulao, Rawa Gede, and Cikoneng agroforestry land because there are more plant or animal remains in the soil in coffee agroforestry in Cisuren.

The average total nitrogen value based on the research in Table 3 for coffee agroforestry land was 0.68%. In contrast, on complex agroforestry land, the total N value was 0.51% for Cibulao, 0.67% for Rawa Gede, 0.56% for Cikoneng, and 0.98% for Cisuren. Total nitrogen in the soil is the overall level of nitrogen in the soil, including different nitrogen sources, namely ammonium, nitrite, and nitrate. Soil nitrogen content varies widely and is influenced by other factors such as climate, vegetation, topography, and physical and chemical properties of the soil, the normal standard of N (Nitrogen) is 0.21 to 0.5 for

plants. (Wawan, 2017; Nopasgiart *et al.*, 2020). Available K on coffee agroforestry land in the Upper Ciliwung Watershed is 610.6 in Cibulao, 87.5 in Rawa Gede, 306.9 in Cikoneng, and 31.1 in Cisuren. The high available K content was likely due to the addition of organic materials to the soil. Applying potassium fertiliser to soil with low potassium content increases soil K content (Azka *et al.*, 2023). Furthermore, available P_2O_5 on coffee agroforestry land is highest in Cibulao (187.8), while it is lowest in Cisuren (22.5) (Balai Penelitian Tanaman Industri dan Penyegar, 2017). In general, the optimal soil for Arabica coffee plants has sufficient to high available P content. An increase in available soil phosphorus (P) was associated with increased coffee production. Available P supports coffee plant growth and productivity because P within the plant influences the uptake of other essential nutrients that support coffee growth and development (Simbolon *et al.*, 2020).

Assessment of Actual and Potential Land Suitability for Coffee Agroforestry

Coffee agroforestry in the Upper Ciliwung Watershed consists of the Cibulao, Cikoneng, Rawa Gede, and Cisuren areas. Based on the results of the assessment of land characteristics and soil properties at the research site, an evaluation of land suitability and land potential was conducted to determine the inhibiting factors and constraints on coffee agroforestry cultivation. Actual land suitability assessment refers to the current suitability of land for specific land uses based on current land conditions and coffee agroforestry management practices. This coffee agroforestry land suitability assessment considers current land use, soil properties,

Table 3: Measurement results of C-organic, total N, available K, and available P_2O_5 at the research site

Land Unit	C-organic	Total N	Available K	Available P_2O_5
Cibulao	6.00	0.51	610.6	187.8
Rawa Gede	7.59	0.67	87.5	39.2
Cikoneng	6.39	0.56	306.9	38.6
Cisuren	17.33	0.98	31.1	22.5

Source: Fitri *et al.* (2024)

and factors that affect land capability. While potential land suitability refers to the future suitability of land for certain uses based on soil properties and inherent land characteristics, it requires improvement, treatment, and management actions to improve the ideal land quality and potential land suitability. Therefore, by considering actual and potential land suitability, coffee agroforestry land management can manage land based on information about land use and coffee agroforestry practices to improve sustainable land use by focusing on soil and water conservation principles. Tables 4 to 7 present the assessment of coffee agroforestry land suitability in the Upper Ciliwung Watershed and the land evaluation results for Cibulao, Cikoneng, Rawa Gede, and Cisuren.

The results of land suitability evaluation for coffee agroforestry in Cibulao (Table 4) show that the average temperature (°C) is moderately suitable (S2), rainfall (mm), soil texture, cation exchange capacity (cmol) is highly suitable (S1),

soil pH is marginally suitable (S3), C-organic (%), total N, available K, available P_2O_5 are highly suitable (S1), and erosion hazard is moderately suitable (S2). Table 4 shows that the actual land suitability class for arabica coffee agroforestry is almost suitable (S3; nr), with the limiting factor being nutrient retention, namely pH. Soil acidity occurs because of the rapid weathering of minerals and rocks and leaching. This limiting factor can be improved through the provision of organic materials and liming. The soil fertility status of coffee agroforestry land in Cibulao is low. This is because this land experiences nutrient leaching due to high rainfall in the tropics. Hilly slopes and a lack of land cover make the land prone to erosion, especially during rain. Land observations at the research site indicated furrow erosion and small landslides. However, because the soil solution was still relatively deep, the resulting erosion hazard remained in the mild to moderate category.

Table 4: Land suitability of robusta coffee plants in agroforestry at Cibulao

Land Characteristics	Data Value	Actual Land Suitability	Improvement Efforts	Potential Land Suitability
Temperature (tc)				
Average temperature (°C)	16.2–26.8	S2	Creating shade	
Water availability				
Rainfall/year (mm)	2,557–3,065	S1		
Rooting media				
Soil texture	Silty clay	S1		
Nutrient retention (nr)				
Cation exchange capacity	36.02	S1		
pH	4.53	S3	Calcification	S2
C-organic	6.00	S1	++	
Nutrient availability				
Total N	0.51	S1		
Available K	610.6	S1		
Available P_2O_5	187.8	S1		
Erosion hazard (eh)				
Slopes	8–15	S2	Making mounds retaining cut slope	
Assessment results		S3 nr, eh		

Note: (+) = Moderate management effort; (++) = High management effort; S1 = Very suitable; S2 = Quite suitable; S3 = Marginally compliant

Table 5: Land suitability of arabica coffee plants in agroforestry in Cikoneng

Land Characteristics	Data Value	Actual Land Suitability	Improvement Efforts	Potential Land Suitability
Temperature (tc)				
Average temperature (°C)	16.2–26.8	S2	Creating shade	
Water availability				
Rainfall/year (mm)	2,557–3,065	S1		
Rooting media				
Soil texture	Silty clay	S1		
Nutrient retention (nr)				
Cation exchange capacity	25.45	S1		
pH	5.00	S2	Calcification +	S1
C-organic	7.59	S1		
Nutrient availability				
Total N	0.67	S1		
Available K	87.5	S1		
Available P ₂ O ₅	39.2	S1		
Erosion hazard (eh)				
Slopes	8–15	S2	Making mounds retaining cut slope	S1
Assessment results		S2 nr, eh		

Note: (+) = Moderate management effort; (++) = High management effort; S1 = Very suitable; S2 = Quite suitable; S3 = Marginally compliant

The results of the land suitability assessment for coffee agroforestry in Cikoneng in Table 5 show that the average temperature (°C) but improvement efforts are needed by making shade or protective plants, rainfall (mm) is very suitable (S1), soil texture clayey loam is very suitable (S1), cation exchange capacity (cmol) is very suitable (S1), soil pH is moderately suitable (S2) so that improvement efforts are needed through liming to improve soil pH, C-organic (%), total N, available K, available P₂O₅ are highly suitable (S1), and erosion hazard is moderately suitable (S2). However, improvement efforts are needed through the creation of retaining mounds to cut slopes so that the potential land suitability becomes suitable (S1).

The results of the evaluation of land suitability for coffee agroforestry in Rawa Gede (Table 6) show that the average temperature (°C) is quite suitable (S2) so that it requires shade plants as an improvement effort, rainfall (mm), soil texture, cation exchange capacity (cmol) is

very suitable (S1), soil pH is marginally suitable (S3) so that improvement is needed through lime application so that soil pH becomes neutral, C-organic (%), total N, available K, available P₂O₅ is very suitable (S1). At the same time, erosion hazard is very marginal (S3), so it requires improvement efforts through terracing.

The results of the assessment of land suitability for coffee agroforestry in Cisuren (Table 7) show that the average temperature (°C) is quite suitable (S2), improvement efforts need to be made shading, rainfall (mm), soil texture, cation exchange capacity (cmol) is very suitable (S1), Soil pH is a limiting factor because it is marginally suitable (S3) so that improvement efforts are needed through liming so that potential land suitability becomes S1, C-organic (%), total N, available K, available P₂O₅ is very suitable (S1). Erosion hazard is marginally suitable (S3) as a limiting factor, so improvement efforts are needed by making terraces.

Table 6: Land suitability of arabica coffee plants in agroforestry in Rawa Gede

Land Characteristics	Data Value	Actual Land Suitability	Improvement Efforts	Potential Land Suitability
Temperature (tc)				
Average temperature (°C)	16.2–26.8	S2	Creating shade	
Water availability				
Rainfall/year (mm)	2,557–3,065	S1		
Rooting media	Silty clay			
Soil texture		S1		
Nutrient retention (nr)				
Cation exchange capacity	24.46	S1		
pH	4.98	S3	Calcification ++	S2
C-organic	6.38	S1		
Nutrient availability				
Total N	0.56	S1		
Available K	306.9	S1		
Available P ₂ O ₅	38.6	S1		
Erosion hazard (eh)				
Slopes	16-25	S3	Making terraces ++	S2
Assessment results	S3 nr, eh			

Note: (+) = Moderate management effort; (++) = High management effort; S1 = Very suitable; S2 = Quite suitable; S3 = Marginally compliant

Table 7: Land suitability of arabica coffee plants in agroforestry areas in Cisuren

Land Characteristics	Data Value	Actual Land Suitability	Improvement Efforts	Potential Land Suitability
Temperature (tc)				
Average temperature (°C)	16.2–26.8	S2	Creating shade	
Water availability				
Rainfall/year (mm)	2,557–3,065	S1		
Rooting media				
Soil texture	Silty clay	S1		
Nutrient retention (nr)				
Cation exchange capacity	38.85	S1		
pH	4.11	S3	Calcification ++	S2
C-organic	17.33	S1		
Nutrient availability				
Total N	0.98	S1		
Available K	31.1	S1		
Available P ₂ O ₅	22.5	S1		
Erosion hazard (eh)				
Slopes	16–25	S3	Making terraces ++	S2
Assessment results	S3 nr, eh			

Note: (+) = Moderate management effort; (++) = High management effort; S1 = Very suitable; S2 = Quite suitable; S3 = Marginally compliant

Figures 4 and 5 present the mapping of actual and potential land suitability for coffee agroforestry. Recommendations for improvement measures were provided for each location based on the actual land suitability class, which led to the determination of the potential land suitability class (Figure 5). The actual land suitability class in Cibulao was classified as marginally suitable (S3), with soil nutrient retention, specifically soil pH, identified as the primary limiting factor. In Cikoneng, the actual land suitability is classified as moderately suitable (S2), and improvement efforts are recommended through the construction of contour bunds to interrupt slope runoff. In Rawa Gede, land suitability is categorised as marginally suitable (S3), with erosion hazard as the dominant limiting factor; therefore, terracing structures are recommended to improve land conditions. Similarly, actual land suitability in Cisuren was classified as marginally suitable (S3), primarily limited by erosion hazards, necessitating terracing measures to enhance land suitability for coffee agroforestry (Figure 4).

Cikoneng can be improved to a highly suitable class (S1) by implementing the recommended improvement measures for areas initially classified as moderately suitable (S2). The areas of Cibulao, Rawa Gede, and Cisuren improved to moderately suitable (S2) after corrective action, primarily addressing soil nutrient retention limitations. Prior to these interventions, the locations were classified as marginally suitable (S3).

Development of Coffee Agroforestry in the Upper Ciliwung Watershed

Coffee agroforestry has emerged as a nature-based solution for mitigating the impacts of climate change, while simultaneously providing sustainable forest utilisation opportunities for rural farmers, particularly in the context of Indonesia's social forestry policy governance (Pramulya *et al.*, 2025). Therefore, coffee agroforestry development should integrate ecological and agronomic considerations to ensure farmers achieve adequate yields while maintaining long-term environmental

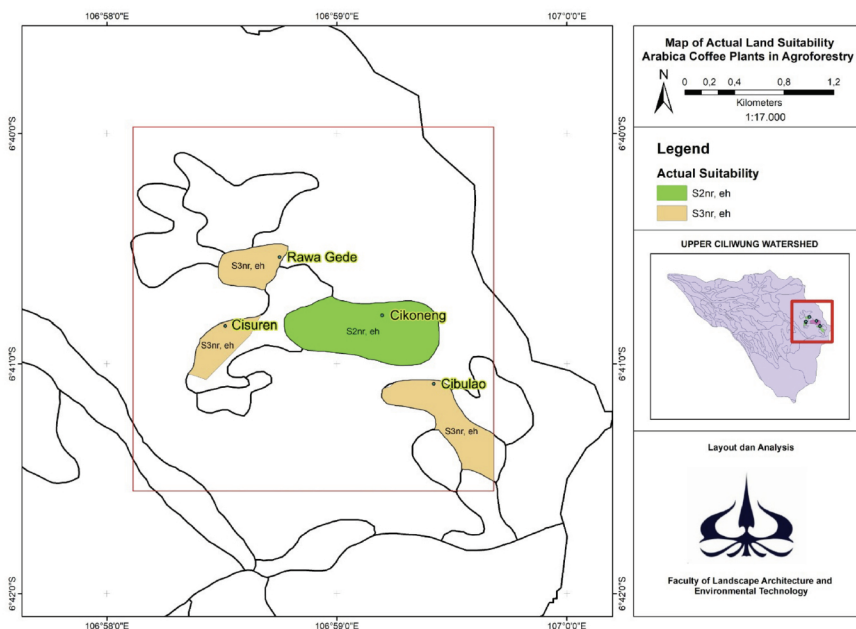


Figure 4: Actual land suitability map for coffee agroforestry in the Upper Ciliwung Watershed
Source: Authors (2025)

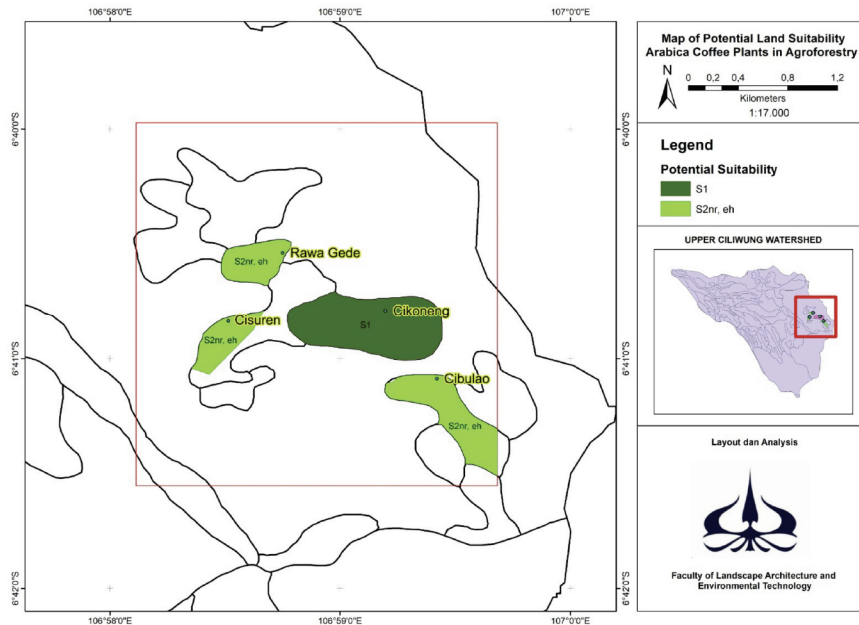


Figure 5: Potential land suitability map for coffee agroforestry in the Upper Ciliwung Watershed
Source: Authors (2025)

sustainability. Coffee agroforestry in the Upper Ciliwung Watershed includes two types of coffee: Robusta in Cibulao and Arabica in Cikoneng, Rawa Gede, and Cisuren. Although agroforestry practices are already established in the area, the present land suitability assessment provides insights into their ecological appropriateness and long-term sustainability. Soil acidity was identified as the primary limiting factor, followed by slope-based erosion risk, both of which varied across the four locations. Therefore, management practices should be adjusted based on the specific limitations of each site.

Areas with steeper slopes, such as Cibulao, Rawa Gede, and Cisuren, would have a higher potential for erosion. Additional conservation measures, such as contour planting, mulching, and increased ground cover, are necessary to minimise soil degradation (Adetunji *et al.*, 2020; Bogunović & Filipović, 2023; Mondaca *et al.*, 2024). Differences in soil pH, organic carbon content, and nutrient availability suggest the need for location-specific soil fertility management

to sustain coffee productivity. These findings indicate that while the agroforestry structural pattern is appropriate, management intensity and conservation practices should be adjusted to the local land characteristics at each site. For example, the soil in Cikoneng requires less calcification because of its higher pH.

The combination of coffee agroforestry components used in this study followed a horizontally dispersed plant combination pattern. Horizontal distribution of plants in coffee agroforestry is achieved by planting tree species along the land perimeter to provide shade, boundaries, and woody components, and by planting annual crops in aisles. Plants combined for the development of coffee agroforestry in the Upper Ciliwung Watershed are plants that generally exist in the research location, including *Coffea canephora* (robusta coffee), *Coffea arabica* (arabica coffee), *Musa* sp. (banana), *Agathis dammara* (dammar), *Persea americana* (avocado), *Toona sureni* (suren toon), and *Pinus merkusii* (pine).

This configuration supports microclimate regulation and partial soil protection (de Carvalho *et al.*, 2021) while utilising endemic species. The existing agroforestry systems reflect the basic ecological principles of shade-based coffee cultivation. Soil acidity and nutrient status would also affect the growth of associated shade and annual crops. For instance, *Musa* sp. require adequate potassium and well-drained soils for optimal growth (Bhalerao *et al.*, 2018). In contrast, woody species tend to show varying tolerances to soil acidity and nutrient limitation (Wei *et al.*, 2023), which may apply to *Persea americana* and *Toona sureni*. Therefore, the measured soil characteristics have broad implications for the overall productivity and stability of agroforestry systems.

Integrating agroforestry practices can strengthen food security because these systems typically produce a variety of crops and fruits in addition to coffee, ensuring a more consistent and reliable food supply (Garedew *et al.*, 2019; Breitler *et al.*, 2022). By diversifying income sources through the sale of coffee and other tree products, farmers can improve their livelihoods and reduce poverty (Pramulya *et al.*, 2023). However, economic benefits alone do not guarantee sustainability. Compatibility between crop requirements and land characteristics remains a critical determinant. Although the present study primarily assessed coffee suitability, the results provide a preliminary basis for evaluating the ecological compatibility of companion species in agroforestry systems. Therefore, rather than merely maintaining the existing agroforestry structure, these findings support developing a site-adaptive management model that integrates slope-based conservation strategies and soil fertility optimisation. Such an approach would strengthen both the ecological resilience and long-term livelihood sustainability in upstream watershed areas. Future studies should expand land suitability evaluations beyond coffee to include associated species, thereby supporting the development of a more comprehensive and adaptive agroforestry management model for the Upper Ciliwung Watershed.

Conclusion

Based on the assessment of land characteristics conducted at the study sites of Cibulao, Cikoneng, Rawa Gede, and Cisuren within the Upper Ciliwung Watershed, recorded temperatures ranged from 16.2°C to 26.8°C, and annual rainfall ranged from 2,557 mm to 3,065 mm. The soil texture across the sites was classified as clayey loam. Organic matter availability was higher in Cisuren than in the agroforestry lands of Cibulao, Rawa Gede, and Cikoneng. The Cation Exchange Capacity (CEC) values ranged from 24.46 me/100 g in Cikoneng to 38.85 me/100 g in Cisuren. The land suitability analysis of coffee agroforestry in the Upper Ciliwung Watershed indicated that the land units of Cibulao, Rawa Gede, and Cisuren were classified as marginally suitable (S3). In contrast, the Cikoneng land unit was classified as moderately suitable (S2). The limiting factors for the Cibulao land unit were acidic soil pH and low soil fertility; for the Rawa Gede land unit, low pH and high erosion risk; for the Cisuren land unit, low pH and low soil fertility; and for the Cikoneng land unit, low pH and erosion hazards. After implementing the recommended land improvement measures, the Cibulao, Rawa Gede, and Cisuren units improved to moderate suitability (S2), while the Cikoneng unit improved to highly suitable (S1).

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Conflict of Interest Statement

The authors declare no conflict of interest.

References

- Abdillah, A., Lubis, K. S., & Mukhlis. (2018). Perubahan beberapa sifat kimia tanah dan pertumbuhan tanaman jagung (*Zea mays* L.) akibat pemberian limbah kertas

- rokok dan pupuk kandang ayam di tanah ultisol. *Jurnal Agroekoteknologi FP USU*, 6(3), 442–447. <https://doi.org/10.32734/ja.v6i3.2371>
- Adetunji, A. T., Ncube, B., Mulidzi, R., & Lewu, F. B. (2020). Management impact and benefit of cover crops on soil quality: A review. *Soil and Tillage Research*, 204, Article 104717. <https://doi.org/10.1016/j.still.2020.104717>
- Affan, M., & Zayadi, H. (2024). Soil quality in land suitability analysis of coffee agroforestry in Patokpici Village, Wajak District, Malang Regency. *Journal of Coffee and Sustainability*, 1(3), 112–117. <https://doi.org/10.21776/ub.jcs.2024.01.03.03>
- Ariandi, R., Ichsan, M., Sabri, A., & Mukti, J. (2025). Agroforestry systems based on land suitability in social forestry areas in Barru Regency, South Sulawesi. *Gorontalo Journal of Forestry Research*, 8(2), 61–76. <https://doi.org/10.32662/gjfr.v8i2.4440>
- Azka, M. H., Abubakar, Y., & Karim, A. (2023). Hubungan antara karakteristik lahan dan produksi kopi robusta di Kabupaten Pidie. *Jurnal Ilmiah Mahasiswa Pertanian*, 8(4), 648–697.
- Balai Penelitian Tanaman Industri dan Penyegar. (2017). *Persiapan dan kesesuaian lahan tanaman kopi*. Kementerian Pertanian. <http://balittri.litbang.pertanian.go.id>
- Bangun, F. B., Wawan, W., & Qomar, N. (2022). Evaluation of land suitability for agroforestry development based on liberika coffee in Kedabu Rapat Village, Meranti Islands Regency. *Jurnal Agronomi Tanaman Tropika (Juatika)*, 4(2), 361–370. <https://doi.org/10.36378/juatika.v4i2.828>
- Bhalerao, V. P., Deshpande, A. N., & Bansal, S. K. (2018). Potassium dynamics in Inceptisols as influenced by graded levels of potash for banana: I. Potassium fractions. *Communications in Soil Science and Plant Analysis*, 49(15), 1886–1895. <https://doi.org/10.1080/00103624.2018.1485929>
- Bilen, C., El Chami, D., Mereu, V., Trabucco, A., Marras, S., & Spano, D. (2022). A systematic review on the impacts of climate change on coffee agrosystems. *Plants*, 12(1), Article 102. <https://doi.org/10.3390/plants12010102>
- Bogunović, I., & Filipović, V. (2023). Mulch as a nature-based solution to halt and reverse land degradation in agricultural areas. *Current Opinion in Environmental Science & Health*, 34, Article 100488. <https://doi.org/10.1016/j.coesh.2023.100488>
- Breitler, J.-C., Etienne, H., Lérans, S., Marie, L., & Bertrand, B. (2022). Description of an Arabica coffee ideotype for agroforestry cropping systems: A guideline for breeding more resilient new varieties. *Plants*, 11(16), Article 2133. <https://doi.org/10.3390/plants11162133>
- Cheserek, J., & Gichimu, B. (2012). Drought and heat tolerance in coffee: A review. *International Research Journal of Agricultural Science and Soil Science*, 2(12), 498–501. <https://www.interestjournals.org/articles/drought-and-heat-tolerance-in-coffee-a-review.pdf>
- de Carvalho, A. F., Fernandes-Filho, E. I., Daher, M., Gomes, L. de C., Cardoso, I. M., Fernandes, R. B. A., & Schaefer, C. E. G. R. (2021). Microclimate and soil and water loss in shaded and unshaded agroforestry coffee systems. *Agroforestry Systems*, 95(1), 119–134. <https://doi.org/10.1007/s10457-020-00567-6>
- Direktorat Jenderal Perkebunan. (2016). *Statistik perkebunan Indonesia 2015–2016*.
- Djaenudin, U. D., Marwan, H., Subagyo, H., & Hidayat. (2003). *Kriteria kesesuaian lahan untuk komoditas pertanian*. Pusat Penelitian Tanah dan Agroklimat.
- Ehrenbergerová, L., Šenfeldr, M., & Habrová, H. (2017). Impact of tree shading on the microclimate of a coffee plantation: A case study from the Peruvian Amazon. *Bois et Forêts Des Tropiques*, 334(4), 13–22.

- <https://doi.org/10.19182/bft2017.334.a31488>
- Fitri, R., Simangunsong, N. I., & Nuraida. (2022). Identifikasi karakteristik biofisik DAS Ciliwung Tengah. *Jurnal Arsitektur ARCADE*, 6(1), 59–63. <https://doi.org/10.31848/arcade.v6i1.881>
- Fitri, R., Simangunsong, N. I., Danniswari, D., & Taki, H. M. (2024). Coffee agroforestry for soil erosion control in the upstream of Ciliwung Watershed, West Java, Indonesia. *Environment Asia*, 17(2), 64–77. <https://doi.org/10.14456/ea.2024.21>
- Garedew, W., Lemessa, F., & Pinard, F. (2019). Landscape context and plot features influence the epidemics of coffee leaf rust (*Hemileia vastatrix*) in southwest Ethiopia. *Archives of Phytopathology and Plant Protection*, 52(1–2), 71–89. <https://doi.org/10.1080/03235408.2019.1580>
- Hidayat, A., Dharmawan, A. H., & Pramudit, A. D. (2017). Kelayakan usaha budidaya kopi Cibulao dalam Program Pengelolaan Hutan Bersama Masyarakat. *Jurnal Risalah Kebijakan Pembangunan Pertanian dan Lingkungan*, 4(2), 85–95. <https://doi.org/10.29244/jkebijakan.v4i2.22028>
- Iscaro, J. (2014). The impact of climate change on coffee production in Colombia and Ethiopia. *Global Majority E-Journal*, 5(1), 33–43. https://www.american.edu/cas/economics/ejournal/upload/iscaro_accessible.pdf
- Kath, J., Mittahalli Byrareddy, V., Mushtaq, S., Craparo, A., & Porcel, M. (2021). Temperature and rainfall impacts on robusta coffee bean characteristics. *Climate Risk Management*, 32, Article 100281. <https://doi.org/10.1016/j.crm.2021.100281>
- Kome, G. K., Tabi, F. O., Enang, R. K., & Silatsa, F. B. T. (2020). Land suitability evaluation for oil palm (*Elaeis guineensis* Jacq.) in coastal plains of Southwest Cameroon. *Open Journal of Soil Science*, 10(7), 257–273. <https://doi.org/10.4236/ojss.2020.107014>
- Li, T., Zhao, L., Duan, H., Yang, Y., Wang, Y., & Wu, F. (2020). Exploring the interaction of surface roughness and slope gradient in controlling rates of soil loss from sloping farmland on the Loess Plateau of China. *Hydrological Processes*, 34(2), 339–354. <https://doi.org/10.1002/hyp.13588>
- Masnang, A., Jannah, A., Hasibuan, R. S., & Fitri, R. (2023). Water holding capacity and soil organic carbon in teak (*Tectona grandis* Linn. F) agroforestry. *Journal of Sustainability Science and Management*, 18(7), 1–10. <https://doi.org/10.46754/jssm.2023.07.001>
- Maulana, A. S. (2022). Pendapatan petani dan efisiensi pemasaran kopi robusta (*Coffea* sp) di Kecamatan Rumpin, Bogor. *Journal of Agribusiness and Agrotechnology*, 2(2), 9–88. <https://doi.org/10.31938/agrisintech.v2i2.354>
- Mondaca, P., Lebuy, R., Rojas, S., Aguas, J., Celis-Diez, J. L., & Díaz-Siefer, P. (2024). Contour furrowing reduces erosion and enhances soil moisture on semiarid hillslopes. *Geoderma Regional*, 38, Article e00826. <https://doi.org/10.1016/j.geodrs.2024.e00826>
- Moreira, T. R., da Silva, S. F., da Silva, N. B., dos Santos, G. M. A. D. A., & dos Santos, A. R. (2020). Global warming and the effects of climate change on coffee production. In Pereira, L. L., & Moreira, T. R. (Eds.), *Quality determinants in coffee production* (pp. 65–100). Springer International Publishing.
- Mukhlis, Sariffudin, [PERHATIAN: Letakkan parap initial nama bagi Sariffudin], & Hanum, H. (2011). *Kimia tanah teori dan aplikasi*. Universitas Sumatera Utara Press.
- Mustawa, Abdullah, S. H., & Putra, G. M. D. (2017). Analisis efisiensi irigasi tetes pada berbagai tekstur tanah untuk tanaman sawi (*Brassica juncea*) [Efficiency analysis of drip irrigation on various soil textures for mustard greens (*Brassica juncea*)]. *Jurnal Ilmiah Rekayasa Pertanian dan Biosistem*,

- 5(2), 408–421. <https://doi.org/10.29303/jrpb.v5i2.56>
- Ostovari, Y., Honarbakhsh, A., Sangoony, H., Zolfaghari, F., Maleki, K., & Ingram, B. (2019). GIS and multi-criteria decision-making analysis assessment of land suitability for rapeseed farming in calcareous soils of semi-arid regions. *Ecological Indicators*, 103, 479–487. <https://doi.org/10.1016/j.ecolind.2019.04.051>
- Prabowo, R., & Subantoro, R. (2018). *Analisis tanah sebagai indikator tingkat kesuburan lahan budidaya pertanian di Kota Semarang*. Universitas Wahid Hasyim.
- Pramulya, R., Bantacut, T., Noor, E., Yani, M., Zufajrin, M., Setiawan, Y., Pulunggono, H. B., Sudrajat, S., Anne, O., Anwar, S., Adinurani, P. G., Siregar, K., Prasetyo, H., Harsono, S. S., Novita, E., Rahmah, D. M., Huu, N. N., Agustia, D., & Rasyid, M. I. (2023). Carbon footprint calculation of net CO₂ in agroforestry and agroindustry of Gayo Arabica Coffee, Indonesia. *Jordan Journal of Biological Sciences*, 16(2), 335–343. <https://doi.org/10.54319/jjbs/160218>
- Pramulya, R., Dahlan, D., Asy'Ari, R., Gustawan, A. H., Dzulfagar, A., Novita, E., Sutrisno, A., & Rahmah, D. M. (2025). Assessment of Gayo agroforestry coffee characteristics and carbon stock potential in Mumuger social forestry area, Central Aceh Regency. *Trees, Forests and People*, 20, 1–13. <https://doi.org/10.1016/j.tfp.2025.100818>
- Rahmawaty, Ismail, M. H., Rauf, A., Batubara, R., Sitorus, E. W. E., Simamora, Z., & Ginting, E. F. (2023). Land characteristics and land suitability assessment for *Styrax* sp. in Humbang Hasundutan Regency, North Sumatra, Indonesia. *Heliyon*, 9(7), 1–16. <https://doi.org/10.1016/j.heliyon.2023.e16936>
- Rahmawaty, Marpaung, R. M. E., Batubara, R., & Rauf, A. (2021). Land suitability for kemenyan cultivation in Sari Laba Jahe Village, Sibiru-biru Sub-district, Deli Serdang District, North Sumatra Province. *IOP Conference Series: Earth and Environmental Science*, 752, Article 012040. <https://doi.org/10.1088/1755-1315/752/1/012040>
- Risaldi, S., Pata'dungan, Y. S., & Zainuddin, R. (2023). Identifikasi sifat fisika tanah pada penggunaan lahan kakao di Instalasi Penelitian dan Pengkajian Teknologi Pertanian Desa Sidindi III. *Jurnal Agrotekbis*, 11(1), 132–141.
- Ritung, S., Nugroho, K., Mulyani, A., & Suryani, E. (2011). *Petunjuk teknis evaluasi lahan untuk komoditas pertanian*. Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian.
- Ritung, S., Wahyunto, Agus, F., & Hidayat, H. (2007). *Panduan evaluasi kesesuaian lahan*. Balai Penelitian Tanah dan World Agroforestry Centre.
- Sadiq, F. K., Ya'u, S. L., Aliyu, J., & Maniyunda, L. M. (2023). Evaluation of land suitability for soybean production using GIS-based multi-criteria approach in Kudan Local Government area of Kaduna State Nigeria. *Environmental and Sustainability Indicators*, 20(2), 1–10. <https://doi.org/10.1016/j.indic.2023.100297>
- Sagiarti, T., Okalia, D., & Markina, G. (2020). Analisis C-Organik, nitrogen, dan C/N tanah pada lahan agrowisata Bekenjaya. *Agrosains dan Teknologi*, 5(1), 11–18. <https://doi.org/10.24853/jat.5.1.11-18>
- Saputra, M. H., & Lee, H. S. (2021). Evaluation of climate change impacts on the potential distribution of *Styrax sumatrana* in North Sumatra, Indonesia. *Sustainability*, 13(2), Article 462. <https://doi.org/10.3390/su13020462>
- Simbolon, L. E. (2020). Korelasi-regresi hubungan ketinggian tempat, kemiringan lereng dan sifat kimia tanah terhadap produksi kopi arabika di Kecamatan Bonatua Lunasi, Kabupaten Tobasa, Sumatera Utara. *Jurnal Online Agroekoteknologi*, 8(1), 1–9.

- Sudomo, A., & Widiyanto, A. (2017). Produktivitas serasah sengon (*Paraserianthes falcataria*) dan sumbangannya bagi unsur kimia makro tanah. In *Prosiding Seminar Nasional Geografi UMS*.
- Tadesse, M., & Negese, A. (2020). Land suitability evaluation for sorghum crop by using GIS and AHP techniques in Agamsa sub-watershed, Ethiopia. *Cogent Food & Agriculture*, 6(1), 1–18. <https://doi.org/10.1080/23311932.2020.1743624>
- Tamaradewi, R. N., Miftah, H., & Yoesdiarti, A. (2019). Analisis nilai tambah dan strategi pengembangan usaha kopi (*Coffea* sp.) di Kelompok Tani Hutan Cibulao Hijau. *Jurnal Agribisains*, 5(2), 43–144. <https://doi.org/10.30997/jagi.v5i2.2322>
- Wawan. (2017). *Buku ajar pengelolaan bahan organik*. Unsri Press.
- Wei, H., Shan, X., Wu, L., Zhang, J., Saleem, M., Yang, J., Liu, Z., & Chen, X. (2023). Microbial cell membrane properties and intracellular metabolism regulate individual level microbial responses to acid stress. *Soil Biology and Biochemistry*, 177, Article 108883. <https://doi.org/10.1016/j.soilbio.2022.108883>