Fertility assessment of land for coffee plantation development in the Argopuro mountain area in Jember district East Java Indonesia

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Abstract. Coffee plantations in the Argopuro Mountains region of Jember Regency, East Java, are relatively old, having been planted during the Dutch colonial era. The purpose of this study was to assess soil fertility and land suitability for coffee cultivation in this region. Soil surveys and soil sampling were conducted at 50 locations across the coffee plantations. Soil samples were analyzed at the Jember State Polytechnic Soil Laboratory. Laboratory analysis are soil texture, organic carbon, soil pH, CEC, and nitrogen, phosphorus, and potassium. Soil fertility status was determined based on soil fertility value criteria from *Bogor Soil and Climate Research Center*, Indonesia, and land suitability for coffee plants was determined based on the criteria of the *Indonesian Coffee and Cocoa Research Center.* The results showed that the coffee land in the survey area is classified as low to moderate in fertility. The soil development has entered the *senile stage* to *final stage*. Land suitability for coffee cultivation ranges from *Very Suitable* (S1) to *Moderately Suitable* (S2). For future, organic matter management and increased N, P, and K nutrients are required. The research are very necessary for the improvement and development of coffee plants in the future.

1. Introduction

Land fertility evaluation is an assessment of a land's characteristics to determine its potential, thus maximizing its use. Land use that does not meet its capabilities can lead to land degradation. Therefore, land evaluation is crucial to ensure that land is used according to its capabilities [3]; [11]. One method frequently used to assess soil fertility is through soil analysis or soil testing. Five soil fertility parameters were used in this study to assess soil fertility status: CEC; base saturation (BS); organic carbon; and total soil P and K content, as per the technical guidelines for soil fertility evaluation [10]; [13].

Coffee is a long-established plantation crop in Indonesia and holds significant economic value. The country is one of the world’s leading coffee producers, following Colombia, Brazil, and Vietnam. Indonesia produces approximately 600,000 tons of coffee annually, with more than 80% cultivated through smallholder-managed land [6]. Two major coffee species are widely known: Arabica and Robusta. In Indonesia, Robusta dominates production, contributing 87.1% of total national output [12].

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East Java is among the coffee-producing provinces in Indonesia, contributing around 7.48% or 35,814 tons per year to national production [5]. However, according to [12], East Java experienced a substantial production decline between 2018 and 2019, reaching -23.82%. A similar trend was reported by [13], showing an additional decrease of approximately -10.28% in 2021–2022. This decline has inevitably affected national coffee supply for both export and domestic consumption. The reduction in production is attributed not only to the impacts of the COVID-19 pandemic but also to suspected degradation in land quality, as many coffee plantations in the region originate from older, inherited estates.

The slopes of the Argopuro Mountains have historically served as a significant coffee plantation area since the Dutch colonial era. The region is administratively managed by four districts, with Jember Regency occupying the largest portion compared to Bondowoso, Situbondo, and Probolinggo (Oktasari, 2014). Given this background, evaluating soil fertility status and land suitability for coffee cultivation in the Argopuro region has become essential. This study also aims to assess land potential for future development of coffee-based farming.

The findings are expected to support local governments and farmers in optimizing coffee cultivation on the slopes of Mount Argopuro in Jember. Enhancing land use and improving cultivation practices will help increase coffee production, thereby strengthening the regional economy and improving community welfare.

The primary objective of this study is to assess land potential as a basis for developing coffee-based farming systems in the Argopuro area of Jember, and to optimize coffee cultivation to increase farm productivity. Another objective is to map potential land for coffee development, covering existing land characteristics, plantation conditions, potential expansion areas, post-harvest handling and downstream processing, as well as socio-economic and cultural aspects.

2. Materials and Methods

2.1. Time and Place

The research was conducted over four months, from October 2022 to January 2023. Field surveys and soil sampling were systematically performed across multiple locations within the Argopuro area of Jember Regency, encompassing seven sub-districts known for existing coffee plantations and high potential for coffee cultivation. Soil analysis for all collected samples was conducted at the Soil Laboratory and Integrated Bioscience Laboratory of Politeknik Negeri Jember. The key soil parameters analyzed included: texture, organic carbon content, soil pH, Cation Exchange Capacity (CEC), and the content of macro-nutrients: nitrogen (N), phosphorus (P), and potassium (K).

2.2. Materials and tools

The materials and tools utilized for land surveying and soil sampling activities include books and stationery, soil survey equipment (such as an *altimeter*, *clinometer*, and *compass*), as well as soil sampling equipment (including a *Belgie-type soil drill*, *hoe*, *guide knife*, and sampling rings).

2.3. Implementation of research

The research was carried out in several stages of activity:

2.3.1.Survey Coordination and Preparation.

Prior to the field survey, the implementation team conducted coordination activities to outline the workflow, identify survey locations and soil sampling points, and determine the types of soil analyses to be performed in the laboratory.

2.3.2.Land Survey and Soil Sampling.

Land surveys and soil sampling were carried out at 50 locations across seven sub-districts: Sumber Baru (4 locations), Tanggul (9 locations), Bangsalsari (8 locations), Panti (11 locations), Sukorambi (7 locations), Arjasa (6 locations), and Jelbuk (5 locations). These locations were selected based on geographic location, characteristics, existing coffee plantation distribution, and planned coffee development areas as identified by the East Java Provincial Plantation Office.
Soil sampling was conducted using the composite sampling method. Samples were collected from a depth of 0–60 cm using a soil auger and a hoe. The collected soils were homogenized, placed into plastic bags weighing approximately 1 kg, labeled with sample identification numbers, and transported to the laboratory for further analysis.

2.3.3.Soil preparation and analysis in the laboratory.

In the laboratory, the soil samples were air-dried for four days in the preparation room, due to rainfall conditions at the time of sampling. After drying, the samples underwent soil analysis as detailed in Table 1. Each parameter was analyzed three times (triplicate) to ensure data accuracy.

Table 1. Type of Analysis, Analysis Method and Units

No.	Type of analysis	Method	Units
1	Soil texture	Hydrometer	%
2	C-organic	700 ^oC ashing	%
3	pH	Electrode, actual	
4	CEC	NH_4 asetat Saturation	me/100 gr
5	N-Total	Kjeldahl (SNI-7030-2004)	%
6	P_2O_5	Olsen	ppm
7	K_2O	Olsen	ppm

2.3.4.Evaluation of soil analysis results.

Based on the soil analysis results presented in Table 1, an evaluation of soil fertility status and land suitability for coffee cultivation was conducted. Soil fertility status was determined using the fertility value criteria established by the Bogor Soil and Climate Research Center, Indonesia (Appendix Table 3) [10]. Fertility status is classified as very high (vh), high (h), medium (m), low (l), and very low (vl).
Land suitability for coffee was assessed according to the criteria of the Indonesian Coffee and Cocoa Research Center (ICCRC), as shown in Appendix Table 4 [9]. Suitability classes include very suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N).

3. Results and Discussion

Based on the soil analysis results and their categorization according to soil fertility value criteria established by the Bogor Soil and Climate Research Center, along with the subsequent evaluation of land suitability status for coffee cultivation using guidelines from the Indonesian Coffee and Cocoa Research Center (ICCRC) [9], the following findings were obtained (Table 2).

Table 2. Results of soil analysis and land suitability status for coffee plants

No	Location / Sub-istrict	pH	N-total (Kjeldahl)	P_2O_5 (Olsen)	K_2O (Olsen)	C-Organic (%)	CEC (me/100gr)	Soil Texture
			(%)	(ppm)	(me/100g)			
1	Sumber Baru	5.67 **(S1)**	0,31 **(m, S1)**	11.67 **(m, S2)**	0.25 **(l)**	0.43 **(l, S3)**	12.62 **(l, S2)**	Sandy Loam **(S1)**
2	Tanggul	6.08 **(S1)**	0,24 **(m, S1)**	14.18 **(m, S2)**	0.30 **(l)**	0.59 **(l, S3)**	17.84 **(m, S3)**	Sandy Loam **(S1)**
3	Bangsal Sari	5.67 **(S1)**	0.19 **(l, S2)**	15.03 **(m, S1)**	0.55 **(m)**	0.85 **(l, S3)**	13.82 **(l, S2)**	Clay Sand **(S2)**
4	Panti	5.55 **(S1)**	0.15 **(l, S2)**	6.37 **(l, S3)**	0.18 **(l)**	0.23 **(l, S3)**	11.38 **(l, S2)**	Sandy Loam **(S1)**
5	Sukorambi	5.79 **(S1)**	0.16 **(l, S2)**	9.58 **(l, S3)**	0.25 **(l)**	0.35 **(l, S3)**	16.80 **(l, S1)**	Sandy Loam **(S1)**
6	Arjasa	6.04 **(S2)**	0.46 **(m, S1)**	11.69 **(m, S1)**	0.45 **(m)**	0.61 **(l, S3)**	18.25 **(m, S1)**	Sandy Loam **(S1)**
7	Jelbuk	5.97 **(S1)**	0.28 **(m, S1)**	12.41 **(m, S2)**	0.78 **(m)**	0.45 **(l, S3)**	19.38 **(m, S1)**	Loam **(S1)**

Notes : **l** = low; **m** = medium; **S1** = *Very suitable*; **S2** = *Moderately suitable*; **S3** = *Marginal suitable.*

3.1. Soil pH.

Table 2 presents the soil pH across all survey locations falls within the slightly acidic range (5.5–6.5). According to ICCRC criteria, this pH range is classified as *Very Suitable (S1)* for coffee cultivation. The only exception was survey location 6 (Arjasa District), which was categorized as *Moderately Suitable (S2)*. Consequently, the soil pH values across all study areas remain highly suitable for the establishment and development of coffee. This range aligns precisely with the optimal soil pH requirement for coffee cultivation, which is documented to be between 5.5 and 6.5 [2].

3.2. Macro Nutrients Status (N, P, K)

The macronutrient fertility status (N, P, and K) presented in Table 2 generally ranges from *medium (m)* to *low (l)*. This condition is expected to improve through appropriate soil management practices, including the application of organic matter and inorganic N, P, and K fertilizers. Areas with low nitrogen (N) status include Bangsalsari, Panti, and Sukorambi Districts, classified as *Moderately Suitable (S2)* for coffee. Locations with low potassium (K) status—particularly Panti and Sukorambi—fall under the *Marginally Suitable (S3)* category. Phosphorus (P) fertility also ranges from *medium (m)* to *low (l)*, with land suitability varying between *Very Suitable (S1)* and *Marginally Suitable (S3)*. The sub-districts categorized as S3 for P availability are Panti and Sukorambi.

Despite the generally low to medium macronutrient status, the survey area remains suitable for coffee cultivation. However, achieving optimal and sustainable productivity requires improved management of N, P, and K nutrients. As reported in [6], low soil fertility can be enhanced through better land management practices, including appropriate fertilization and the addition of organic matter. Proper nutrient management and maintenance of soil organic matter are essential components of soil management for coffee cultivation [4].

3.3. Soil organic matter

The soil analysis results show that all survey locations had *low (l)* organic carbon content. This indicates that the land on the slopes of the Argopuro Mountains in Jember Regency has undergone intensive use over an extended period.

Historically, the Argopuro slopes have been utilized for coffee plantations since the Dutch colonial era [5, 9]. This long-standing agricultural exploitation is suspected to be the primary cause of the depleted organic matter content in the area. Furthermore, the low C-organic status points toward a potential lack of adequate organic matter management practices (such as compost application or crop residue incorporation) in recent cultivation cycles.

3.4. Cation Exchange Capacity (CEC) of Soil

Table 2 also presents the CEC values of soils at all survey sites range from medium (m) to low (l), with land suitability status varying from Very Suitable (S1) to Marginally Suitable (S3) for coffee cultivation.

This low CEC value indicates that the soil in the survey area has entered the advanced soil development stage (old soil) which is characterized by low macronutrient content, especially K nutrients, and low organic matter content [8]. Furthermore, for highly productive coffee cultivation, established guidelines [2] stipulate that the ideal soil should exhibit CEC values above 15 mE/100 g soil, a pH range of 5.5–6.5, and medium to high potassium (K) content. Based on these criteria, improvements in soil fertility management are necessary to enhance and sustain soil productivity for coffee farming in the study area.

3.5. Soil Texture

Table 2 indicates that soils across the survey locations predominantly exhibit fine textures, specifically *clay-loam*. This suggests that the soils have reached a mature stage of development, ranging from the *Senile Stage* (semi-mature) to the *Final Stage* (mature soil). Despite this condition, land suitability evaluations for coffee [9] reveal that most survey locations fall within the *Very Suitable (S1)* category. Only the Bangsalsari sub-district is classified as *Moderately Suitable (S2)*.

Field observations confirmed that the solum (soil depth) used as the rooting zone for coffee plants is relatively deep—exceeding 100 cm and has a medium texture, commonly loam. This aligns with [5], who reported that soils with relatively fine textures such as clay-loam, sandy clay loam, and silty clay loam are highly suitable for coffee cultivation. Similarly, [2] emphasized that loam-textured soils are generally favorable for Arabica coffee, while [1] also concluded that medium to fine textural classes are ideal for coffee plant growth.

3.6. Recommendation

Based on the findings derived from the soil analysis and the subsequent evaluation of land suitability potential for developing coffee plantations conducted in the Argopuro area of Jember Regency, the following specific management recommendations are proposed:

3.6.1.Area expansion potential.

The potential for the development and expansion of smallholder coffee plantations in Jember Regency—particularly in the seven surveyed districts located on the slopes of the Argopuro Mountains—remains promising. Although several survey sites exhibit low parameter values (l) and are classified as *Marginally Suitable (S3),* appropriate land management interventions can improve these parameters to medium (m), thereby increasing the land suitability status from *Moderately Suitable (S2)* to *Very Suitable (S1)*.

3.6.2.Improvement of soil fertility levels.

Efforts to enhance soil fertility must be carried out consistently and according to a structured schedule. Increasing soil organic carbon content requires the greater use of organic fertilizers. In addition, balanced applications of inorganic fertilizers containing N, P, and K are necessary to improve the soil's macronutrient levels in a sustainable and efficient manner.

3.6.3.Improvement of cultivation techniques.

One of the cultivation practices requiring significant improvement is branch management, which is aimed at maximizing the number of productive branches. This technique is strongly recommended and should be implemented continuously to support optimal coffee plant productivity.

3.6.4.Implementation of dense planting systems and polyclonal (Robusta).

Land optimization and improved planting efficiency are essential to increase plant population density. This can be achieved through the use of triangular planting systems with a spacing of 3 meters. For Robusta coffee, the application of a polyclonal planting system is also recommended to enhance genetic diversity and productivity.

3.6.5.Plant rejuvenation.

In areas or plantations dominated by old or damaged coffee plants, rejuvenation efforts are urgently required. Replanting with improved varieties is expected to significantly increase productivity and ensure long-term sustainability.

3.6.6.Improvement of harvesting and post-harvest processes.

Enhancing the harvesting and post-harvest handling of coffee is crucial for improving the overall quality and competitiveness of the final product. Post-harvest improvements should prioritize the adoption and refinement of wet-processing techniques, which are known to enhance coffee quality and market value..

3.6.7.Participatory mapping.

It is highly recommended to conduct participatory mapping activities involving members of local farmer groups in delineating and mapping their respective coffee plots. Such maps will enable farmer groups to independently assess, plan, and manage the potential for development and expansion of their coffee farming areas.

4. Conclusion

The land fertility assessment in the Argopuro Mountain area, Jember District, East Java, indicates that the soil characteristics generally support coffee plantation development, although several limiting factors were identified. The evaluated physical and chemical soil properties showed variations in soil texture, pH, organic matter content, and nutrient availability, which influence land suitability for coffee cultivation. Based on the land suitability analysis, certain areas were classified as moderately suitable, while others require specific management interventions to improve soil quality. Therefore, appropriate land management practices, including soil fertility improvement and site-specific cultivation strategies, are necessary to optimize coffee plantation development and ensure sustainable production in the study area.

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Appendices

Table 3. Criteria for Soil fertility value

Soil parameter	Unit	Value				
		Very Low (vl)	**Low (l)**	**Medium (m)**	**High (h)**	**Very High (vh)**
C	%	< 1	1 -2	2 - 3	3 - 5	> 5
N	%	< 0.10	0.10 – 0.20	0.21 – 0.50	0.51 – 0.75	> 0.75
C/N	-	< 5	5 - 10	11 - 15	16 - 25	> 25
P_2O_5 HCl 25 %	mg/100g	< 15	15 - 20	21 - 40	41 - 60	> 60
P_2O_5 Bray	ppm P	< 4	5 - 7	8 - 10	11 - 15	> 15
P_2O_5 Olsen	ppm P	< 5	5 - 10	11 - 15	16 - 20	> 20
K_2O HCl 25 %	mg/100g	< 10	10 - 20	21 - 40	41 - 60	> 60
CEC	me/100 g-soil	< 5	5 - 16	17 - 24	25 - 40	> 40
Cations :						
Ca	me/100 g-soil	< 2	2 - 5	6 - 10	11 - 20	> 20
Mg	me/100 g-soil	< 0.3	0.4 - 1	1.1 – 2.0	2.1 – 8.0	> 8.0
K	me/100 g-soil	< 0.1	0.1 – 0.3	0.4 – 0.5	0.6 – 1.0	> 1
Na	me/100 g-soil	< 0.1	0.1 – 0.3	0.4 – 0.7	0.8 – 1.0	> 1
Basa-Saturation (BS)	%	< 20	20 - 40	41 - 60	61 - 80	> 80
Al-Saturation	%	< 5	5 -10	11 - 20	20 - 40	> 40
Mineral Reserves	%	< 5	5 -10	11 - 20	20 - 40	> 40
Salinity	mm hos/cm	< 1	1 - 2	2 - 3	3 - 4	> 4
Na-*intercangeable*	%	< 2	2 - 3	5 - 10	10 - 15	> 15

Source : [10]

Table 4. Technical criteria for land suitability for Robusta, Arabica, and Liberica coffee

No	Indicator	Land Suitability Class			N (Not suitable)
		S1 (Very suitable)	S2 (Moderately	S3 (Marginal	
1	2	3	4	5	6
1.	c-climate				
	Annual rainfall (mm)	1.500-2.000	1.250	1.250	< 1.000
			2.000-2.500	2.500-3.000	> 3.000
	Long dry months (mt)	2-3	3-4	4-5	> 5
	(<60 mm/mt)			1-2	< 1
2.	t-Elevation (m-asl)				
	Robusta	300-500	500-600	600-700	> 700
			100-300	0-100	
	Arabika	1.000-1.500	850-1.000	650-850	< 650
			1.500-1.750	1.750-2.000	> 2.000
	Liberika	300-500	600-800	8800-1000	> 1000
			0-300		
3.	s-slope (%)	0-8	8-25	25-45	> 45
4.	r-Phisycal properties of soil				
	Effective depth (cm)	> 150	100-150	60-100	< 60
	Texture	Sandy loam	Clay sand	Clay	*Sand*
		Clay loam	Sandy clay		*Havy clay*
		Silty loam	Silty clay		
		Silty clay loam			
	Percentage of rocks on the surface (%)	-	0-3	3-15	> 15
5.	**d-flooding**	-	-	1-7 days	> 7 days
	Drainage class	good	Rather good	Rather bad	*excessive*
				bad	*very bad*
			A	Rather excesssive	
6.	n-Chemical properties of soil (0-30 cm)				
	pH	5.5-6.0	6.1-7.0	7.1-8.0	> 8.0
			5.0-5.4	4.0-4.9	< 4.0
	C-Organic (%)	2-5	1-2	0,5-1	< 0.5
			5-10	10-15	> 15
	CEC (me/100 g)	> 15	10-15	5-10	< 5
	BS (%)	> 35	20-35	< 20	-
	N (%)	> 0.21	0.1-0.2	< 0.1	-
	P2O5-available (ppm)	> 16	10-15	< 10	-
	Aldd (me %)	> 0.3	0.1-0.3	< 0.1	-
7.	x-Toxicity				
	Salinity (mm hos/cm)	< 1	1-3	3-4	> 4
	Al-saturation (%)	< 5	5-20	20-60	> 60

Source : [9]