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Potential Land Suitability for Cardamom (*Elettaria cardamomum*) Cultivation in Topos District, Lebong Regency

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ABSTRACT

Land suitability evaluation is crucial for determining the characteristics and quality of land to support cardamom cultivation. This study aims to map land suitability classes and assess the potential for cardamom cultivation in Topos District, Lebong Regency. Conducted from June to December 2023, the research employed survey methods, land classification, and descriptive presentation of results. Tools such as Avenza Map, soil augers, GPS, clinometers, Munsell Soil Color Charts, and laboratory soil analysis were used, supplemented with secondary data sources. Land suitability was determined using a matching technique for individual land characteristics. The results indicated that the actual land suitability for cardamom in Topos District is predominantly in the S3 class, covering 11,722.95 hectares (71.43%), limited by factors such as nutrient availability and steep slopes. Potential land suitability was classified into four categories: S1 (1,825.94 hectares, 11.12%), S1rc (727.35 hectares, 4.43%), S2rc (2,342.88 hectares, 14.27%), and S2 (5,326.63 hectares, 32.46%). Recommended improvements include liming, fertilization, organic matter application, and soil and water conservation to enhance land suitability. The most suitable areas for cardamom cultivation include shrubland, rice fields, open land, and mixed dryland farming. Economic analysis revealed a favorable B/C ratio of 1.11, signifying profitability. This study highlights the considerable potential for cardamom cultivation in Topos District, provided that sustainable land management practices are implemented. The findings underscore the crop's economic viability, offering valuable insights for policymakers and farmers seeking to optimize land use while fostering economic growth and reducing environmental impact.

Keywords: *Cardamom, economic analysis, land suitability,potential*

INTRODUCTION

The Topos District, located within the Bukit Barisan mountain range, encompasses 16,409 hectares with elevations from 400 to 1,700 meters above sea level. Characterized by hilly topography, the district's economy is heavily reliant on agriculture, with coffee as the main cash crop (Badan Pusat Statistik, 2021). However, traditional coffee cultivation on steep slopes has contributed significantly to soil erosion and land degradation, primarily due to sparse plant cover (Dariah et al., 2005). These challenges necessitate the exploration of complementary crops, such as cardamom (Elettaria cardamomum), which may alleviate environmental impacts and diversify local income sources.

Cardamom's adaptability to shaded environments and ability to grow as a companion crop offer potential conservation benefits. By intercepting rainfall and reducing surface runoff, cardamom planting under existing canopy cover can mitigate erosion while enhancing soil stability (Mukhlisa, 2015). This plant, which thrives in well-drained soils at altitudes of 200–1,000 meters with moderate sunlight, aligns well with Topos District's agro-climatic conditions (Prasetyo, 2004; Pasally, 2019). Moreover, cardamom has a promising economic outlook due to its high market demand for both essential oils and dried fruit, which are valuable in various medicinal, culinary, and aromatic applications (Suratman, 1997; Direktorat Tanaman Sayuran dan Obat, 2019).

Given these advantages, a scientific assessment of land suitability for cardamom cultivation in Topos District is essential. By evaluating specific land characteristics (soil pH, slope, and moisture) and matching them with cardamom's growth requirements, this study aims to classify land suitability and identify optimal cultivation areas. This research not only offers development recommendations for farmers but also provides a foundation for sustainable land-use strategies that balance economic growth with environmental conservation in Lebong Regency (Djaenudin *et al*., 2011).

MATERIALS AND METHODS

This research was conducted from June to December 2023 in Topos District, Lebong Regency, Bengkulu Province. The sampling took place in Topos District, located at coordinates 102°22'-102°30' E and 3°03'20"-3°17' S. Soil sample analysis was performed at the Soil Science Laboratory, Faculty of Agriculture, University of Bengkulu.

The equipment used in this study can be categorized into three groups: GIS analysis tools, field survey tools, and laboratory soil sample analysis tools. GIS analysis equipment included a laptop, printer, Windows operating system, and ArcGIS 10.8 software. Field survey tools consisted of an Avenza map, field knives, sample rings, clinometers, Munsell Soil Color books, and other necessary field instruments. Laboratory tools were used for analyzing soil's physical and chemical properties. The materials used included a 1:80,000 administrative map from the Indonesian Geospatial Information Agency, a 1:80,000 land unit map, and a 1:80,000 slope map derived from a Digital Elevation Model (DEM) with 30 m resolution, obtained from the US Geological Survey using ArcGIS 10.8. Annual rainfall data were sourced from the Meteorology, Climatology, and Geophysics Agency (BMKG). Land suitability guidelines for cardamom cultivation were based on technical manuals (Ritung, 2011), along with laboratory analysis materials.

This research consists of pre-survey stages, field surveys, data tabulation, land suitability classification, preparation of land suitability maps, and preparation of a final report. The pre-survey stage is a preparation stage. The research began by collecting the necessary tools and materials, arranging permits from universities and village officials so that the research could run smoothly, and making land map unit work maps (SPL) to determine sampling points by overlaying scale 1 slope maps: 80,000 and a 1:80,000 scale land unit map using ArcGIS 10.8 software which was then selected based on certain considerations (purposive sampling) to conduct a field survey.

The second stage is a field survey which includes several activities, namely observation, measurement, and taking soil samples. To determine land physical and chemical variables. During the field survey, farmer interviews were also conducted to obtain data on the crops cultivated by farmers to determine the economic value of the community.

The third stage is soil sample analysis carried out at the Soil Science Laboratory to measure texture, CEC, N-total, pH, and C-organic. The analysis method is presented in Table 1.

Table 1. Laboratory analysis methods

No	Observed variable	Analytical method
1.	Texture	*Hydrometer*
2.	CEC	Distillation and Titration
3.	N-Total	*Kjeldahl*
4.	pH	*Elektrometri*
5.	C-Organic	*Walkey and Black*

The next stage is the correlation of field data and laboratory analysis. The data obtained were analyzed using the matching method with the cardamom land suitability table obtained from research (Ritung *et al*., 2011) so that the land suitability evaluation and assessment process could be carried out. Data is grouped based on each land quality based on the method developed by FAO (Saputra *et al*., 2016) using 4 order class categories, namely S1: highly suitable, S2: moderately suitable, S3: marginally suitable (Marginally suitable) and N: not suitable (Not suitable). Subclasses are based on limiting factors, namely land characteristics, water availability (wa), rooting media (rc), nutrient retention (nr), nutrient availability (na), and erosion hazard (eh).

The final stage is making a land suitability map based on field observations and laboratory analysis results. Preparation of actual and potential land suitability maps for Cardamom plants in Topos District, Lebong Regency, Bengkulu Province.

The climate data used are rainfall, air temperature and humidity data in Topos District for the last 5 years. Data sourced from BMKG (Meteorology, Climatology and Geophysics Agency) then calculated the average monthly and annual rainfall.

Observation variables in the root media consist of soil texture, effective depth and drainage. Soil texture is observed using the hydrometer method in the laboratory, soil depth is observed directly in the field with several depth measurements measured using a folding ruler. Drainage is observed directly in the field with three drainage classes, namely good, moderate and bad (Intara *et al*., 2011).

Nutrient retention observation variables consist of CEC which is analyzed using the distillation and titration methods, pH is analyzed using the electrometry method, and C-organic is analyzed using the Walkey and Black method (Eviati & Sulaeman, 2009).

Availability of nitrogen (N-total), Phosphorus (P-available), and potassium (potassium exchangeable) nutrients are essential macronutrients that are very much needed in the process of plant growth and development. For the total N analysis method using (Kjehdahl method), P_2O_5 using (Bray method), and K2O using (the flamephotometer method).

Slope steepness, slope shape, and slope length can affect the amount of erosion and surface flow. A slope gradient map is a map that shows the condition of the slope level on land. The slope is the ratio between vertical distance and horizontal distance (Simanjuntak *et al*., 2020). In addition to direct measurements, slope values can also be obtained by calculating DEM (Mahmudi *et al*., 2015).

The socio-economic data used are secondary data obtained using observation and interview methods of people who work as farmers in the research area so that the land area, agricultural production costs, actual commodities, and potential commodities are known. Based on these data, become a reference and direction in the development of Cardamom plants in the research area. The calculation formula for the financial feasibility analysis of farming businesses is as follows.

[B/C Ratio = {TR - TC}/{TC}]

Where:
TR = Total revenue
TC = Total cost
Evaluation Criteria (Putri & Sungkawa, 2021) :

1. B/C Ratio > 1 indicates the business is efficient and feasible.
2. B/C Ratio = 1 indicates a break-even situation.
3. B/C Ratio < 1 indicates inefficiency and that the business is not feasible

RESULTS AND DISCUSSION

General description of research location

Topos District is administratively bordered by several areas such as Kerinci Sebelat National Park Forest (TNKS), Rimbo Pengadang District, South Sumatra Province, and Lebong Sakti District. Topos District is dominated by forest areas as much as 2/3 of the area. Geographically, Topos District is located at 1020 22’- 1020¬30’ East Longitude and 3¬03’20’ - 3¬017’ South Latitude. The area of Topos District is 16409.78 hectares (ha) which is divided into 8 villages, namely, Talang Donok, Talang Donok I, Talang Baru I and II, Suka Negeri, Ajai Siang, and Tik Sirong. Topos District is located at an altitude of 400 - 1700 meters above sea level with climate conditions in the last 5 years in Topos District having an average rainfall of 2,536 mm/year, air temperature of 26.70C, and air humidity ranging from 70-85%. The research location map is presented in Figure 1.

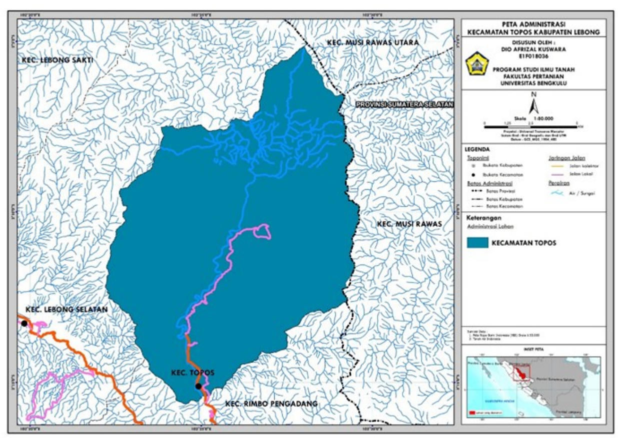

Figure 1. Research location map

Physiographically, some of the people of Topos District are engaged in agriculture, namely in the plantation, rice fields, and horticulture (annual crops) sectors. The population in Topos District in 2020 was 6,435 people or 6.05 percent of the total population of Lebong Regency. The people of Topos District generally work in the agricultural sector, the main source of income for the majority of the people is farming. The most dominant sector is the plantation sector because this sector has the largest area in Topos District, the main commodities in the area are coffee and rice. Some farmers in Topos District, Lebong Regency have started to develop Cardamom plants and generate income even though the percentage of production is not too much, because the community uses Cardamom plants as intercrops between coffee and rubber plants which will later be traded locally or for their consumption. The agricultural sector in the Topos District is still relatively homogeneous. Because most people tend to plant coffee and rice. However, in addition, the Topos District community also plants secondary crops, vegetables, and fruits such as corn, chili, ginger, turmeric, and oranges. The agricultural sector in the area provides extensive employment opportunities for the community to be able toa manage natural resources and land that has not yet been managed in the Topos District.

Land characteristics in Topos District

Topos District consists of six land units, each with varying areas and soil types. The predominant land unit in Topos District is Ma.2.3.4, covering an area of 6,634.16 hectares (40.43%). This unit belongs to the physiographic group of mountainous regions, with parent material derived from coarse and fine sedimentary rocks. The slope class ranges between 25-45%, and the landform is characterized by steep terrain (Darul *et al*., 1989). The soil types developing in this district are predominantly Inceptisols, which are further classified into Dystropepts and Tropaquepts. Dystropepts are a type of Inceptisol with a base saturation of less than 60%, indicating low fertility. In contrast, Tropaquepts are Inceptisols with aquic properties, meaning they are often water-saturated, leading to frequent drainage issues (Hardjowigeno, 2003).

Table 2. Land unit classification and dominant great group in Topos District

Land unit	Dominant great group	Associated great groups	Area (ha)	Percentage (%)
Ma.2.3.4	*Dystropepts*	*Dystropepts, Eutropepts, Humitropepts*	6634,16	40,43
Mq.2.3.3	*Dystropepts*	*Dystropepts, Hapludox, Humitropepts*	3405,74	20,75
Mfq.2.2.3	*Dystropepts*	*Dystropepts, Hapludults*	3266,78	19,91
Af.4.1.1	*Tropaquepts*	*Tropaquepts, Eutropepts*	1386,37	8,45
Hq.1.2.1	*Dystropepts*	*Dystropepts, Hapludults*	1120,36	6,83
Au.2.4.2	*Dystrandepts*	*Dystropepts, Humitropepts, Tropaquepts*	596,37	3,63
	Total		16409,78	10000%

Source: Land Unit Map Sheet 0912 (Bengkulu), Scale 1:250,000

Land unit characteristics

The Af.4.1.1 land unit spans 1,386.37 hectares (8.45%) and belongs to the alluvial group formed by depositional materials such as river deposits, swamp deposits, and colluvial/alluvial deposits resulting from eluviation/colluviation processes from higher surrounding slopes. This alluvial group contains alluvial/colluvial fans located at the foothills, which collect deposits from higher areas. The altitude of this unit ranges between 400 and 500 meters above sea level (MASL).

The Mq.2.3.3 land unit falls within the mountainous group, with highly variable soil-forming materials including fine and coarse sedimentary rocks, as well as acidic intrusive rocks. The soil characteristics exhibit a texture that ranges from fine to coarse, with good drainage and low fertility. The terrain is steep to very steep, and the land is used for primary forest, shrubs, and mixed dryland agriculture. This unit is distributed across mountainous areas with slopes ranging from 8% to 45%, covering 3,405.74 hectares (20.75%).

The Hq.1.2.1 land unit belongs to the hilly group, with soil-forming materials composed of fine and coarse sedimentary rocks, primarily claystone and sandstone. The landscape is characterized by hills and mountains, with slopes ranging from 8% to 25% at altitudes between 400 and 600 MASL, covering an area of 1,120.36 hectares (6.83%). The vegetation and land use are primarily dominated by shrubs and mixed dryland gardens. The primary limiting factors in this hilly group are the very steep slopes and low soil fertility, with the majority of the soil texture being fine (A'yunin, 2008). The distribution of these land units is presented in Figure 2.

Slope gradient is a critical factor to consider in agricultural development, as it directly influences the risk of erosion and landslides. Purba *et al*. (2019) highlight that slope gradient has a strong correlation with soil moisture content and crop productivity. Steep slopes are particularly prone to severe erosion, making them unsuitable for agricultural use (Purnomo *et al*., 2016).

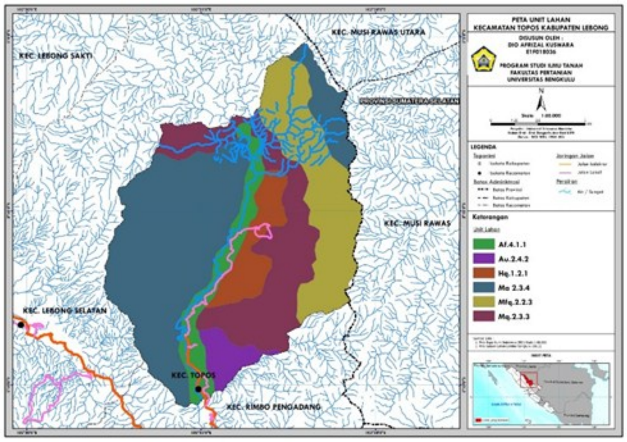

Figure 2. Map of land and soil units

According to Sudibyo & Kosasih (2011), conservation techniques suitable for sloped forest areas include vegetative conservation methods, such as the addition of ground cover plants, construction of infiltration pits, strip planting, crop rotation, and the use of organic materials. Additionally, land under tree canopies can be utilized for growing spices and medicinal plants, such as ginger and galangal, which not only contribute to daily needs but also have economic value (Akiefnawati & Rahayu, 2016). By covering the soil with vegetation, the destructive impact of raindrops on soil aggregates can be reduced, thereby minimizing erosion (Asdak, 2006). The distribution of slope classes is presented in Table 3.

Table 3. Slope class distribution in Topos District

Slope (%)	Slope class	Landform	Area	
			ha	%
0 – 8	1	Flat	238,09	1,45
8 – 15	2	Gentle	1167,45	7,11
15 – 25	3	Moderately Steep	3679,18	22,42
25 – 45	4	Steep	9174,31	55,9
>45	5	Very steep	2151,73	13,11
Total			16409,78	100

Source: Topos District Slope Map, Scale 1:80,000 and Field Survey

The slope classes in Topos District are predominantly characterized by steep slopes (25-45%), covering a vast area of 9,175.31 hectares (55.91%) of the total study area. In contrast, slopes with gradients of 8-15% account for 1,167.45 hectares (7.11%), while moderately steep slopes (15-25%) encompass 3,679.18 hectares (22.42%). Slopes with gradients greater than 45% cover 2,151.73 hectares (13.11%). The smallest area is occupied by flat land (0-8%), with an area of 238.09 hectares (1.45%) of the total study area.

These findings indicate that the topography of Topos District is largely dominated by very steep, steep, and moderately steep slopes, with only small portions of the area classified as gentle or flat. This distribution has significant implications for land use and development, particularly in terms of agricultural suitability and erosion risk. The majority of the region's landforms present challenges for agricultural expansion due to the high susceptibility to erosion on steep slopes. Proper land management and conservation techniques are essential to mitigate these risks.The distribution of slope classes is illustrated in Figure 3.

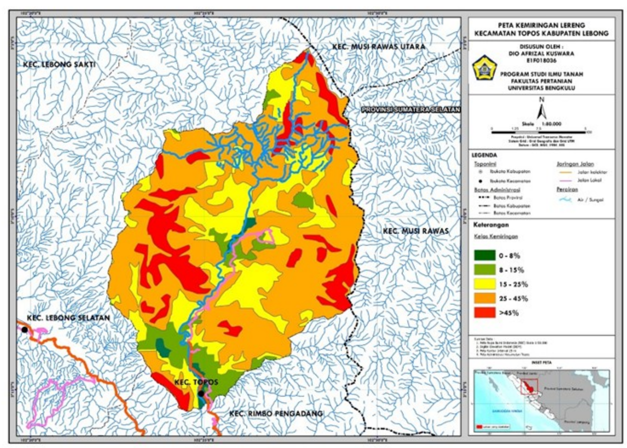

Figure 3. Slope gradient map of Topos District

Land characteristics are crucial factors in ecosystems, particularly for plant growth (Rayes, 2007). Generally, land characteristics include climate, rooting medium, nutrient retention, nutrient availability, land preparation, and erosion potential. Climate is the primary factor in determining the suitability of land for plant growth, and it is typically a fixed variable that cannot be altered.

Soil texture and soil depth are categorized as limiting factors that cannot be modified, whereas soil drainage can still be improved. In the study area, soil drainage is classified as good, with an average depth greater than 60 cm. The soil texture in the region ranges from fine, moderately fine, medium, to moderately coarse, corresponding to land suitability classes S1, S2, and S3.

Plants grow when their nutrient requirements are met by absorbing nutrients through their roots from the soil. For soil to be an ideal rooting medium, it must meet specific criteria, including appropriate soil texture, good drainage, and sufficient effective soil depth. Soil texture and effective soil depth are fixed limitations that cannot be improved, while soil drainage can be enhanced. According to Hanafiah (2014), optimal soil texture for plant growth is a combination of clay and sandy textures.

The chemical properties of the soil, which influence nutrient retention and availability, were also analyzed. These include pH, cation exchange capacity (CEC), organic carbon content, and total nitrogen, which were determined through laboratory analyses. Meanwhile, data on the availability of phosphorus (P -available) and potassium (K exchangeable) were obtained from the land unit information in the 0912 (Bengkulu) map sheet. Overall, the soil pH in Topos District is classified as acidic, ranging between 4.0 and 6.43. The CEC of the soil falls into the S1 class with high values (34.94 meq/100g), total nitrogen levels are within S1 and S3 classes, and organic carbon content is classified as S1.

Land characteristics data are represented by land mapping units (LMUs). The distribution and characteristics of each LMU (Table 4). Based on the analysis, Topos District contains 25 land mapping units. The most dominant LMU is LMU 18, covering 2,117.92 hectares, located in land unit Mq.2.3.3, which has a slope gradient of 25-45% (classified as steep). The smallest LMU is LMU 6, with an area of 58.82 hectares, located in land unit Af.4.1.1, which has a slope gradient of 15-25% (classified as moderately steep). A detailed distribution of the characteristics of each LMU is presented in Table 4.

Land use in Topos District

Topos District is divided into two main areas: Other Use Areas (APL) and Protected Forests (HL). The APL covers a total area of 11,034 hectares and includes secondary forests, mixed dryland agriculture, open land, residential areas, rice fields, and shrublands. In contrast, the Protected Forests encompass 5,377.04 hectares of primary forest.

Land use data was obtained through satellite image interpretation. The district is predominantly characterized by mixed dryland agriculture, which spans 6,618.62 hectares. Given the current land use status, there is significant potential for the development of cardamom (*Elettaria cardamomum*) within the APL areas, specifically in secondary forests, open land, mixed dryland agriculture, and shrublands.

Cardamom cultivation has already been initiated in Topos District, with some plantations established among coffee and rubber tree farms. This existing development indicates a promising potential for expanding cardamom cultivation and suggests that it could be a viable recommendation for further agricultural development in the region.

Primary forests are not suitable for the development of cardamom cultivation as they are designated for conservation purposes. According to Alkaf et al. (2014), the transition of forests into shrublands and mixed gardens represents a significant land-use change. Therefore, it is crucial to exclude primary forests from cardamom development recommendations to prevent further forest degradation.

Residential areas are not recommended for cardamom cultivation due to their use by local communities for housing and related activities. Similarly, rice fields are excluded from consideration as they are dedicated to food production needs.For further details, the land use map can be referred to in Figure 4.

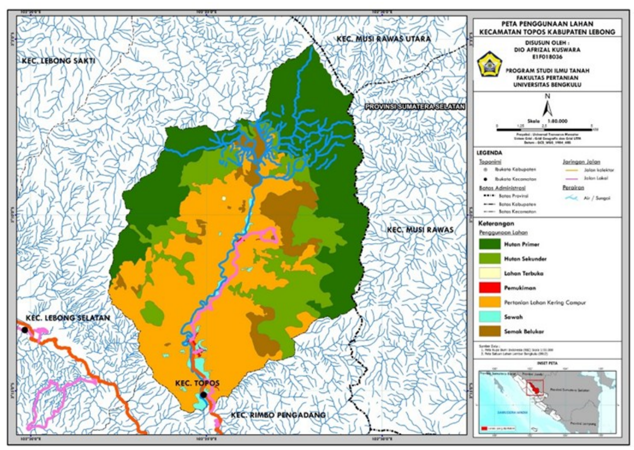

Figure 4. Land use map of Topos District

Current land suitability for Cardamom cultivation in Topos District

Land suitability refers to the adaptability of a particular land area for specific uses, determined by land classes and land use patterns in relation to its potential. This process aims to guide more targeted land use practices (Apena *et al*., 2021). According to Ritung *et al*. (2011), actual land suitability is assessed based on the existing biophysical properties of the soil or land resources, before any necessary inputs or improvements are applied to address existing limitations.

Table 4. The distribution of the characteristics of each LMU

No	Rainfall (mm)	Temperature (^oC)	Depth	Texture	Drainage	pH	CEC	Organic Carbon	Total N	Available P	Exchangeable K	Slope (%)
1	2536	26.7	145	Fine	Good	4.5	23.8	1.9	S	ST	R	>45
2	2536	26.7	110	Fine	Moderately Impeded	4.5	34.94	3.61	SR	S	R	>45
3	2536	26.7	125	Fine	Moderate	4.6	14.15	2.79	ST	R	S	>45
4	2536	26.7	130	Fine	Moderate	4.3	11.35	2.84	T	SR	R	0-8
5	2536	26.7	145	Fine	Good	4.5	23.8	1.9	S	ST	R	0-8
6	2536	26.7	130	Fine	Moderate	4.3	11.35	2.84	T	SR	R	25-45
7	2536	26.7	70	Slightly Coarse	Good	4.9	24.68	2.24	T	R	R	15 - 25
8	2536	26.7	120	Fine	Good	4.22	23.8	1.9	S	SR	R	15 - 25
9	2536	26.7	85	Fine	Moderate	4.72	14.15	1.31	T	SR	R	25 - 45
10	2536	26.7	145	Fine	Good	4.53	23.8	1.9	S	ST	R	15 - 25
11	2536	26.7	110	Fine	Moderately Impeded	4.5	34.94	3.61	SR	S	R	25 - 45
12	2536	26.7	125	Fine	Moderate	4.6	25.71	2.79	ST	R	S	25 - 45
13	2536	26.7	130	Fine	Moderate	4.31	11.35	2.84	T	SR	R	25 - 45
14	2536	26.7	70	Slightly Coarse	Good	4.9	24.68	2.24	T	R	R	15 - 25
15	2536	26.7	85	Fine	Moderate	4.72	14.15	1.31	T	SR	R	25 - 45
16	2536	26.7	145	Fine	Good	4.53	23.8	1.9	S	ST	R	15 - 25
17	2536	26.7	130	Fine	Moderately Impeded	4.5	34.94	3.61	SR	S	R	25 - 45
18	2536	26.7	125	Fine	Moderate	4.6	25.71	2.79	ST	R	S	25 - 45
19	2536	26.7	130	Fine	Moderate	4.31	11.35	2.84	T	SR	R	25 - 45
20	2536	26.7	70	Slightly Coarse	Good	4.9	24.68	2.24	T	R	R	25 - 45
21	2536	26.7	120	Fine	Good	4.22	23.8	1.9	S	SR	R	15 - 25
22	2536	26.7	85	Fine	Moderate	4.72	14.15	1.31	SR	SR	R	8 - 15
23	2536	26.7	145	Fine	Good	4.53	23.8	1.9	S	ST	R	8 - 15
24	2536	26.7	110	Fine	Moderately Impeded	4.5	34.94	3.61	SR	S	R	8 - 15
25	2536	26.7	125	Fine	Moderate	4.6	25.71	2.79	ST	R	S	8 - 15

Notes: SR : very low ; R : low ; S = moderate ; T : high ; ST : very high
Source: Laboratory Analysis of Soil Science. Faculty of Agriculture. University of Bengkulu. and Field Survey

Table 5. Distribution of land use in Topos District

Land Use	Associated Vegetation Type	Area (ha)
Primary Forest	Natural forest vegetation with no human intervention	5,377.04
Secondary Forest	Coffee plantations, low-to-medium vegetation, plantation crops, agroforestry, and other woody plants	2,910.84
Mixed Gardens	Fallow land, fields, orange orchards, and other annual crops	6,618.62
Open Land	Bare land, vegetable crops, grasslands, and meadows	3.87
Residential Areas	Housing, yards, roads, and buildings	69.05
Rice Fields	Rice paddies, wetlands, ponds, and other water bodies	277.34
Shrublands	Shrubs and young bushes	1,155.27
Total		16,409.78

Source: Land Use Map of Topos District and Field Survey

The classification of actual land suitability involves a system where land is categorized based on its current characteristics, without considering additional inputs or modifications required (Tufaila & Alam, 2014). In land evaluation, limitations are categorized into permanent constraints, which cannot be altered, and non-permanent constraints, which can be mitigated through improvements. Table 6 presents information on the classes of current land suitability, providing a comprehensive overview of the land's potential for cardamom cultivation based on its existing conditions.

Land suitability assessment can be conducted either in absolute or relative terms, depending on the current condition of the land (Actual Suitability) or on the land's potential condition after significant improvements (Potential Suitability). These improvements are expected to cause very significant and relatively permanent changes to the land's characteristics, with effects lasting more than 10 years (Brinkman & Smyth, 1973; FAO, 1977). In this context, it is important to consider both the actual and potential suitability in order to make comprehensive land use decisions.

Based on the analysis conducted, three land suitability classes are currently identified. Specifically, SPL 5, 20, 23, and 25 fall under the S2 land suitability class (moderately suitable), with subclasses S2na, S2rc na eh, and S2na eh. The limiting factors for this class include K deficiency, texture, available phosphorus, and slope. The total area covered by this class is 4,123.29 hectares (25.12%). To improve the suitability of this land to class S1 (highly suitable), it is recommended to apply potassium (K) fertilization, phosphorus (P) fertilization, and adopt strip cropping techniques.

Table 6. Classes and Subclasses of actual land suitability and limiting factors

LMU	Class	Subclass	Limiting Factors	Area (ha)	Percentage (%)
-	S1	-	-	-	-
5, 20, 23, 25	S2	S2na, S2rc na eh, S2na eh	Root Media, Nutrient Availability, Erosion Hazard	2,553.29	15.56
4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 21, 22, 24	S3	S3na, S3na eh, S3eh	Nutrient Availability, Erosion Hazard	7,669.51	46.73
1, 2, 3	N	Neh	Erosion Hazard	463.55	2.28
Primary Forest	-	-	-	5,377.04	32.76
Rice Fields	-	-	-	277.34	1.69
Residential Areas	-	-	-	69.05	0.42
Total				16,409.78	100

Source: Potential Land Suitability Map of Topos District, Scale 1:80,000, and Field Survey

Note: Class S1: Highly Suitable; Class S2: Moderately Suitable; Class S3: Marginally Suitable; Class N: Not Suitable

Subclasses: rc - Root Media, nr - Nutrient Retention, na - Nutrient Availability, eh - Erosion Hazard

Meanwhile, LMU 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 21, 22, and 24 fall under the S3 land suitability class (marginally suitable), with subclasses S3na, S3na eh, and S3eh. The limiting factors for this class include available phosphorus, slope, and total nitrogen (N). This class covers an area of 11,722.95 hectares (71.43%). To improve the suitability of this land to class S2 (moderately suitable), measures such as phosphorus and nitrogen fertilization, agroforestry (intercropping), terracing, the construction of water infiltration trenches, and the use of strip cropping are recommended.

On the other hand, LMU 1, 2, and 3 are classified as N (not suitable) under the Neh subclass, with slope being the primary limiting factor. This class covers an area of 563.55 hectares (3.43%), and no land improvement measures are feasible, as these areas are designated for land conservation purposes.

According to Government Regulation No. 6/2007, forest areas with slopes greater than 30% should not be used for agricultural activities. However, preventing communities from engaging in farming on such steep terrain is nearly impossible. Senoaji (2011) highlights that land with slopes between 25% and 45% can be managed for agricultural purposes, provided that soil and water conservation techniques are implemented, as these areas are at high risk of erosion. Further details on the actual land suitability can be found in Figure 5.

In summary, careful management and targeted interventions are crucial in enhancing the land suitability of specific areas, while considering both agricultural potential and environmental conservation.

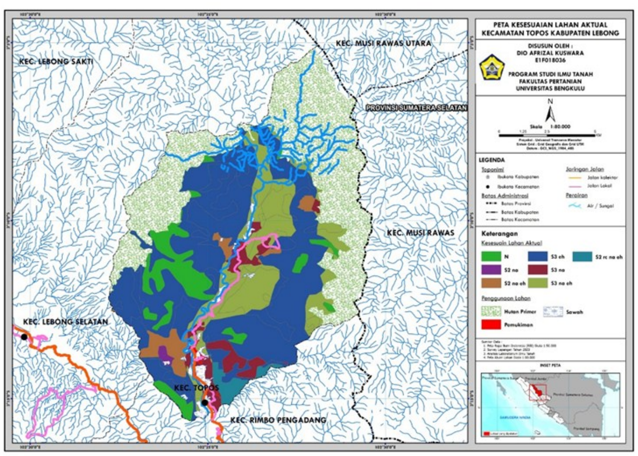

Figure 5. Actual land suitability map of Topos Distric

Potential land suitability for Cardamom cultivation in Topos District

Potential land suitability refers to the suitability of land after certain improvements have been made, tailored to address specific needs. Improvements are aimed at addressing limiting factors, although some of these limiting factors can be improved while others cannot (Rayes, 2007). The land suitability class may increase by one or more levels depending on the extent and effectiveness of the management practices applied.

In this study area, the potential land suitability is predominantly classified as S2 (moderately suitable), covering an area of 7,024.20 hectares (42.80%). In comparison, the highly suitable land class (S1) covers only 1,825.94 hectares (11.12%), while the S1rc subclass accounts for just 727.35 hectares (4.43%). Additionally, the S2rc subclass covers 1,164.96 hectares (7.09%).

To convert actual land suitability into potential suitability, farmers are required to implement specific interventions addressing the limiting factors in each land unit. These interventions may include applying fertilizers, adding organic matter, constructing drainage systems, and adopting agroforestry practices, particularly on land with slopes exceeding 30%. These targeted actions are essential for optimizing land use and improving the productivity of cardamom cultivation.

The potential land suitability map is shown in Figure 6. In conclusion, enhancing the potential land suitability requires a combination of tailored management practices, addressing specific limitations of each land unit, and promoting sustainable agricultural techniques such as agroforestry. This strategic approach will contribute to long-term land productivity and the sustainability of cardamom farming in the region.

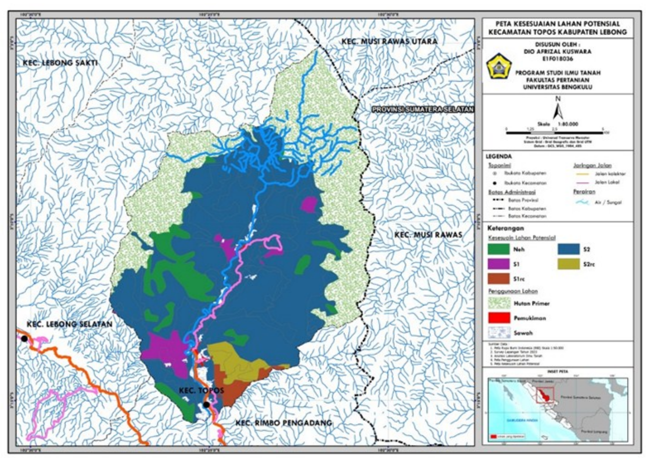

Figure 6. Potential land suitability map of Topos Distric

This results showed same condition with Murugan *et al*. (2022) where the majority of the most successful cardamom plantations are available in Indian cardamom hills (ICH) in the elevation ranging from 700’ to 7000’ above sea level. Nearly half a century ago, the ICH was a typical tropical evergreen forest with enormous biodiversity, including epiphytes. Ruthless regular shade lopping is the foremost essential operation that all planter would like to do. This causes changes in micro and topoclimatic condition along with fast degradation of the forest structure and function. Moreover, Paul *et al*. (2024) showed that the ideal temperature for cardamom cultivation is 15 to 25 ^{o}C and it is grown in forest loamy acidic soil with pH of 5.5 – 6.5. Furthermore, Murugan *et al*. (2023) stated that over the last three decades, the production and productivity of cardamom have shown a steady increase along with the ongoing local climatic change. Maintaining shade levels is essential to addres the adverse effects of increasing surface air temperature coupled with the downward tren of the number of rainy days and elevated soil temperature levels.

Land management recommendations for Topos Subdistrict

Land management is determined by considering the necessary efforts to improve existing limiting factors. These limiting factors are divided into permanent factors, which cannot be altered, such as climate, soil texture, and effective soil depth, and modifiable factors, such as soil acidity and fertility (Mubekti, 2012). It is crucial to focus on both types of limiting factors to achieve optimal land use.

In the study area, land management efforts are primarily directed at overcoming the limiting factors that hinder plant growth. Limiting factors represent the dominant qualities and characteristics of the land that restrict the ability of certain crops to thrive. Addressing these constraints is essential for enhancing agricultural productivity.

One of the key land management practices recommended is the use of organic fertilizers (Shaji *et al*., 2021). Organic fertilizers not only provide essential nutrients for plants but also enhance the soil's ability to retain water and resist surface runoff, which in turn helps reduce erosion. Organic matter improves the soil's water absorption capacity, making it an effective solution for maintaining soil health (Wati *et al*., 2014).

In Topos Subdistrict, several improvement measures can be implemented. For LMU 5, 23, and 25, efforts should focus on addressing deficiencies in exchangeable potassium (K exchangeable) and available phosphorus (P) through fertilization, as well as mitigating erosion risks through the construction of terraces or infiltration trenches. Susila (2013) recommends improving soil chemical properties by incorporating organic fertilizers such as green manure, livestock manure, or compost. Nutrient limitations, particularly for N, P, and K, can also be addressed through targeted fertilization. In LMU 20, management efforts should aim to reduce nutrient limitations and mitigate erosion risks.

For LMU 4, 6, 8, 9, 10, 11, 12, 13, 15, 17, 18, 19, 21, 22, and 24, improvements can be made by applying fertilizers, constructing terraces, adopting intercropping systems (agroforestry), employing strip cropping techniques, and adding organic matter to raise the land to the S2 suitability class. However, for LMU 7 and 14, while some improvements can be made, the limiting factor of soil texture, which cannot be modified, places these areas in the S2rc subclass.

The land most suitable for cardamom cultivation is found in LMU 5, 23, 20, and 25, which fall under the S1 and S1rc suitability classes. Following these, LMU 4, 6, 8, 9, 10, 11, 12, 13, 15, 17, 18, 19, 21, 22, and 24 are categorized under the S2 class, while LMU 7 and 14 are classified as S2rc. Land management for LMU 1, 2, and 3, which are constrained by steep slopes and high erosion risks, is not recommended for agricultural development due to conservation concerns.

The potential land suitability and the specific management steps for each area can be found in Table 7, which provides a comprehensive overview of the recommended improvements. This detailed management plan aims to optimize land use for cardamom cultivation while maintaining environmental sustainability.

The Economic Value Calculation of Cardamom Cultivation (1 ha/3 years)

The Benefit-Cost Ratio (B/C Ratio) is a metric used to assess the profitability of a business by comparing the total revenue (Benefit = B) to the total production costs (Cost = C). This ratio helps determine whether a business is profitable or not, based on the threshold value of B/C. If the ratio exceeds 1, the business is considered profitable, while a value less than 1 indicates that the business is unprofitable (Putri & Sungkawa, 2021). The B/C Ratio is a key financial indicator used to evaluate the feasibility of an agricultural or business project (Bakhtiar *et al*., 2023). A ratio greater than 1 suggests that the benefits or returns generated by the project outweigh the costs incurred, making the project profitable. Conversely, a ratio below 1 indicates that the project operates at a loss, with costs exceeding benefits. Therefore, a B/C Ratio of 1.11 in cardamom cultivation signifies a positive return on investment, justifying the continuation of the farming operations.

In the case of cardamom cultivation over a 3-year period on a 1-hectare plot of land, the calculated B/C ratio is 1.11, which is greater than 1. This indicates that the cardamom farming enterprise is economically viable and worth continuing.

Table 7. Recommendations for land management in Topos District

LMU	Land Suitability		Improvement Measures	Slope (%)	Area (ha)
	Actual	Potential			
1	Neh	Neh	No improvement measures can be applied	>45	301.81
2	Neh	Neh	No improvement measures can be applied	>45	190.29
3	Neh	Neh	No improvement measures can be applied	>45	71.45
4	S3 na	S2	Phosphorus (P) fertilization and Potassium (K) fertilization	0 - 8	88.66
5	S2 na	S1	Potassium (K) fertilization	0 - 8	187.17
6	S3 na eh	S2	Phosphorus (P) and Potassium (K) fertilization. and agroforestry (intercropping)	25 - 45	58.82
7	S3 eh	S2rc	Phosphorus (P) and Potassium (K) fertilization. and construction of terraces or infiltration trenches	15 - 25%	719.65
8	S3 na eh	S2	Improve cation exchange capacity (CEC) with organic matter. Phosphorus (P) and Potassium (K) fertilization. and construction of terraces	15 - 25	500.29
9	S3 na eh	S2	Improve CEC with organic matter. Phosphorus (P) and Potassium (K) fertilization. and agroforestry	25 - 45	446.35
10	S3 eh	S2	Potassium (K) fertilization and construction of terraces	15 - 25	616.07
11	S3 na eh	S2	Construction of drainage channels. addition of organic matter. Phosphorus (P) fertilization. and agroforestry	25 - 45	80.15
12	S3 eh	S2	Phosphorus (P) fertilization and agroforestry	25 - 45	472.34
13	S3 na eh	S2	Phosphorus (P) and Potassium (K) fertilization. and agroforestry	25 - 45	473.29
14	S3 eh	S2rc	Phosphorus (P) and Potassium (K) fertilization. and construction of terraces	15 - 25	945.31
15	S3 na eh	S2	Improve CEC with organic matter. Phosphorus (P) and Potassium (K) fertilization. and agroforestry	25 - 45	221.06
16	S3 eh	S2	Potassium (K) fertilization and construction of terraces	15 - 25	103.5
17	S3 na eh	S2rc	Construction of drainage channels. addition of organic matter. Nitrogen (N) fertilization. and agroforestry	25 - 45	2177.92
18	S3 eh	S2	Phosphorus (P) fertilization and agroforestry	25 - 45	785.99
19	S3 na	S2	Phosphorus (P) and Potassium (K) fertilization. and agroforestry	25 - 45	254.48
20	S2 rc na eh	S1rc	Phosphorus (P) and Potassium (K) fertilization. and agroforestry	25 - 45	1227.35
21	S3 na eh	S2	Improve CEC with organic matter. Phosphorus (P) and Potassium (K) fertilization. and strip cropping	15 - 25	731.97
22	S3 na	S2	Improve CEC with organic matter. Phosphorus (P) and Potassium (K) fertilization	8 - 15	1468.7
23	S2 na eh	S1	Potassium (K) fertilization and strip cropping	8 - 15	1229.61
24	S3 na	S2	Construction of drainage channels. improve CEC with organic matter. Nitrogen (N) and Potassium (K) fertilization. and strip cropping	8 - 15	1578.4
25	S2 na eh	S1	Phosphorus (P) fertilization and strip cropping	8 - 15	1479.16
			Total Area		16409.78

Source: Potential Land Suitability Map of Topos Subdistrict (Scale 1:80.000) and Field Survey

Notes: LMU : land map unit; Land Suitability Classes: S1 (Highly suitable). S2 (Moderately suitable). S3 (Marginally suitable). N (Not suitable); Subclasses: rc (rooting media). nr (nutrient retention). na (nutrient availability). eh (erosion hazard)

CONCLUSION

The actual land suitability for cardamom cultivation in Topos District falls into three land suitability classes: S2, S3, and N. Most of the area (71.43%) is within the S3 class, constrained by limited nutrient availability and erosion hazards. The S2 class covers 25.12%, while unsuitable land (N) spans 3.43%. After improvement efforts—such as fertilization, terracing, water drainage construction, and organic matter application—the potential land suitability is reclassified into four classes: S1, S1rc, S2, and S2rc. With improvements, 11.12% of the land achieves the S1 class, marking it as highly suitable for cardamom. The Benefit-Cost (B/C) ratio of 1.11 indicates that cardamom cultivation is economically viable and could contribute to regional income diversification.

The findings underscore the importance of sustainable land management practices to unlock the potential for cardamom cultivation in Topos District. Enhancing nutrient availability, managing erosion, and maintaining soil health are essential to making cultivation sustainable in hilly terrains. Key areas for cultivation include secondary forests, mixed dryland farming, shrublands, and open lands.

For implementation, targeted training and policy support for soil conservation, organic matter application, and terracing could encourage farmers to adopt these practices. Additionally, subsidies or access to resources could support sustainable expansion. Future research should explore long-term environmental impacts, crop yield optimization, and the potential for integrating other economically viable crops in similar regions. This study provides valuable insights for policymakers and farmers, aiming to optimize land use while supporting economic growth and mitigating environmental degradation.

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