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Land Suitability Evaluation for Rubber Cultivation on Hilly Land in Nagari Sitanang, Lareh Sago HalabanDistrict, Lima Puluh Kota Regency, West Sumatra

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Abstract: This study was conducted to identify the soil characteristics of hilly land, determine the actual and potential land suitability classes for rubber (Hevea brasiliensis), and identify the dominant limiting factors and their respective amelioration measures. The research employed a descriptive survey method involving field observation, soil sampling, laboratory analysis, and a land characteristic matching procedure against the growth requirements of rubber. Four land units were evaluated based on climate, water availability, drainage, root zone media, nutrient retention, erosion hazard, flood hazard, and land preparation. The findings revealed that rainfall, drainage, soil texture, soil depth, flood hazard, surface rock fragments, and rock outcrops were conducive to rubber growth. The principal limiting factors included an annual temperature of 22 °C, acidic to strongly acidic soil pH, low base saturation, low organic carbon content on steep slopes, a high coarse fragment content, and a high erosion hazard. The actual suitability classes obtained were S3-tc,nr for Unit A; S3-tc for Unit B; S3-tc,nr,eh for Unit C; and N-eh for Unit D. Following improvement interventions, Units A and B were upgraded to S2-tc, Unit C remained classified as S3-tc,eh, and Unit D remained classified as N-eh. Based on these results, rubber cultivation is recommended to be prioritized on Land Units A and B, implemented on a limited scale on Land Unit C with the application of intensive soil conservation practices. It is not recommended for Land Unit D due to its permanent topographical constraints.

Keywords: Hevea brasiliensis; Hilly land; Land suitability; Nagari Sitanang

Introduction

Rubber (*HeveabrasiliensisMuell*. Arg.) is a strategic plantation commodity in Indonesia, with the majority of its cultivated area, approximately 88.6%, managed by smallholder plantations (Direktorat Jenderal Perkebunan, 2024). However, national smallholder rubber productivity remains low, with an average declining trend of 3.89% per year from 2016 to 2023, primarily due to a reduction in cultivated area, price fluctuations, and low land productivity One of the major factors contributing to low productivity is the establishment of rubber plantations on land that does not meet the crop's growth requirements (Liu et al., 2017). Rubber trees (Hevea brasiliensis) exhibit tolerance to a wide range of soil types; however, optimal growth and productivity are attained only when the soil meets specific requirements (Djaenudin et al., 2011). According to Hazir et al., (2020), the key parameters governing the success of rubber cultivation include soil texture, effective depth (>100 cm for optimal yield), drainage, soil reaction (pH 4.5–6.5), cation exchange capacity (CEC), base saturation, organic carbon content, and the availability of macronutrients such as nitrogen (N), phosphorus (P), and potassium (K). In highly acidic soils with pH < 4.5, elevated aluminum concentrations and

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low base saturation act as toxic factors that inhibit root development and nutrient uptake.

West Sumatra is one of Indonesia's major rubber-producing regions, with rubber production reaching 122,000 tons in 2023 and a cultivated area of approximately 180,212 ha (Badan Pusat Statistik, 2024). Lima Puluh Kota Regency is among the smallholder rubber development areas in the province, although rubber is not a major plantation commodity compared with cocoa, gambier, robusta coffee, and coconut (Jailani et al., 2025). In Lareh Sago Halaban Subdistrict, rubber has been cultivated for generations on hilly land with slopes ranging from 3 to 15% and annual rainfall of approximately 2,000 mm $year^{-1}$ (Puspita et al., 2024). Nagari Sitanang is the largest nagari in Lareh Sago Halaban Subdistrict, covering 147.68 km^2, or 37.40% of the total subdistrict area. The rubber cultivation area increased slightly from 697 ha in 2022 to 701 ha in 2024. However, rubber production declined from 308 tons to 140 tons during the same period, while productivity decreased from 441.9 kg ha^{-1} to 199.7 kg ha^{-1} (Badan Pusat Statistik Kabupaten Lima Puluh Kota, 2024).This productivity level remains substantially below the potential yield of superior rubber clones, which ranges from 1,500 to 2,500 kg ha^{-1} $year^{-1}$, indicating a productivity gap associated with land characteristics and management practices.

Multazam (2023), reported that hilly land exhibits highly variable soil fertility due to erosion, nutrient leaching, and toposequence differences, often constituting a major constraint on productivity. Furthermore, the conversion of forest to rubber monoculture has been shown to reduce the soil quality index by up to 15.50% relative to natural forest conditions. Therefore, soil characterization prior to the formulation of recommendations for rubber development in hilly areas is imperative, as emphasized by Liu et al. (2017).

Land suitability evaluation offers a systematic approach to address this issue by matching actual land characteristics with crop growth requirements. The framework developed by Djaenudin et al. (2011) categorizes land suitability into four classes: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N). This framework divides limiting factors into two distinct types. The first type encompasses permanent, unmodifiable factors. Examples include steep slopes and heavy clay textures. The second type involves dynamic, modifiable factors. These constraints (e.g., acidic pH, low soil organic carbon, and low base saturation) can be ameliorated through liming, organic matter application, and fertilization (Danniswari et al., 2024; Hehakaya et al., 2020). Researchers have widely applied this approach to rubber plantations across various Indonesian regions, including Pakpak Bharat (Harahap et al., 2020), and Padang Sago, West Sumatra (Nurkhairani & Triyatno, 2025).

Soil fertility in Nagari Sitanang is classified as low. Puspita et al. (2024) reported severely depleted P_2O_5 levels (0.25–16.40 ppm) and low base saturation (2.33–11.1%). However, their study did not correlate these fertility metrics with specific land-suitability classes for rubber cultivation in hilly land. Currently, local farmers rely on generational, traditional practices without scientific land evaluation guidelines. This approach risks agricultural expansion into unsuitable areas. Cultivating rubber on marginal lands without prior suitability assessments demonstrably reduces latex yields and inflicts long-term economic losses on farmers (Nguyen et al., 2020). As the largest administrative village (Nagari) in the region and a significant contributor to regional rubber production, Nagari Sitanang urgently requires land-suitability-based development directives. Local governments need these empirical guidelines to formulate targeted rejuvenation and intensification programs.

Based on the aforementioned context, the novelty of this research lies in integrating the soil characterization of hilly terrains with actual and potential land suitability evaluations for rubber in Nagari Sitanang. Local farmers actively cultivate rubber in this region. However, prior studies have never systematically evaluated its land suitability using a standardized framework. Furthermore, this study bridges the existing research gap regarding specific limiting factors in hilly areas. It analyzes how erosion, soil depth, and coarse-fragment content affect suitability classes within individual land units. This approach generates location-specific amelioration guidelines instead of generic recommendations. Finally, this research delivers practical contributions for agricultural spatial policy in Lima Puluh Kota Regency. It establishes a viable model for evaluating hilly rubber plantations throughout West Sumatra.

The objectives of this study are to (1) identify the soil characteristics of the hilly terrain in Nagari Sitanang, (2) determine the actual and potential land suitability classes for rubber cultivation, and (3) formulate the dominant limiting factors alongside their corresponding amelioration measures.

Method

The study was conducted on hilly land in Nagari Sitanang, Lareh Sago Halaban Subdistrict, Lima Puluh Kota Regency, West Sumatra, Indonesia, located at 00°13′–00°25′ S and 100°37′–100°56′ E. Soil samples collected from the study area were subsequently analyzed in the laboratory.

Materials and Methods

The instruments and supporting data used in the study included administrative maps, soil type maps, slope maps, land use maps, rainfall maps, a Global Positioning System (GPS), clinometer, soil auger, soil sampling rings, Munsell Soil Color Chart, pH meter, and laboratory analytical equipment. The main materials consisted of disturbed and undisturbed soil samples from each soil mapping unit (SMU), along with chemical reagents required for soil analysis.

This study employed a descriptive survey method at a semi-detailed scale (1:25,000 to 1:50,000) based on the Technical Guidelines for Land Evaluation (Djaenudin et al., 2011). Researchers determined soil sampling locations through purposive sampling. This sampling targeted Soil Mapping Units (SMUs) generated by overlaying soil type, slope, and land-use maps in a Geographic Information System (GIS).

The research team conducted the land suitability evaluation using a matching method based on the Law of the Minimum. This principle dictates that the most severe limiting characteristic determines the final suitability class (Djaenudin et al., 2011). The evaluation produces results at two distinct levels: actual suitability (without amelioration) and potential suitability (following the amelioration of modifiable constraints). The system categorizes land suitability into four main classes: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N). Specific subclass symbols indicate the corresponding limiting factors.

Research Procedure

Figure 1 illustrates the research procedure. The preparation phase involved collecting secondary data and delineating a tentative Soil Mapping Unit (SMU) map. Secondary data comprised thematic maps, regional monographs, and ten-year climate records (rainfall and air temperature) from the nearest meteorological station. Fieldwork involved soil augering. The research team recorded morphological properties including soil color, texture, structure, consistency, effective depth, and drainage conditions. They measured slope gradients using a clinometer and recorded geographical coordinates via GPS.

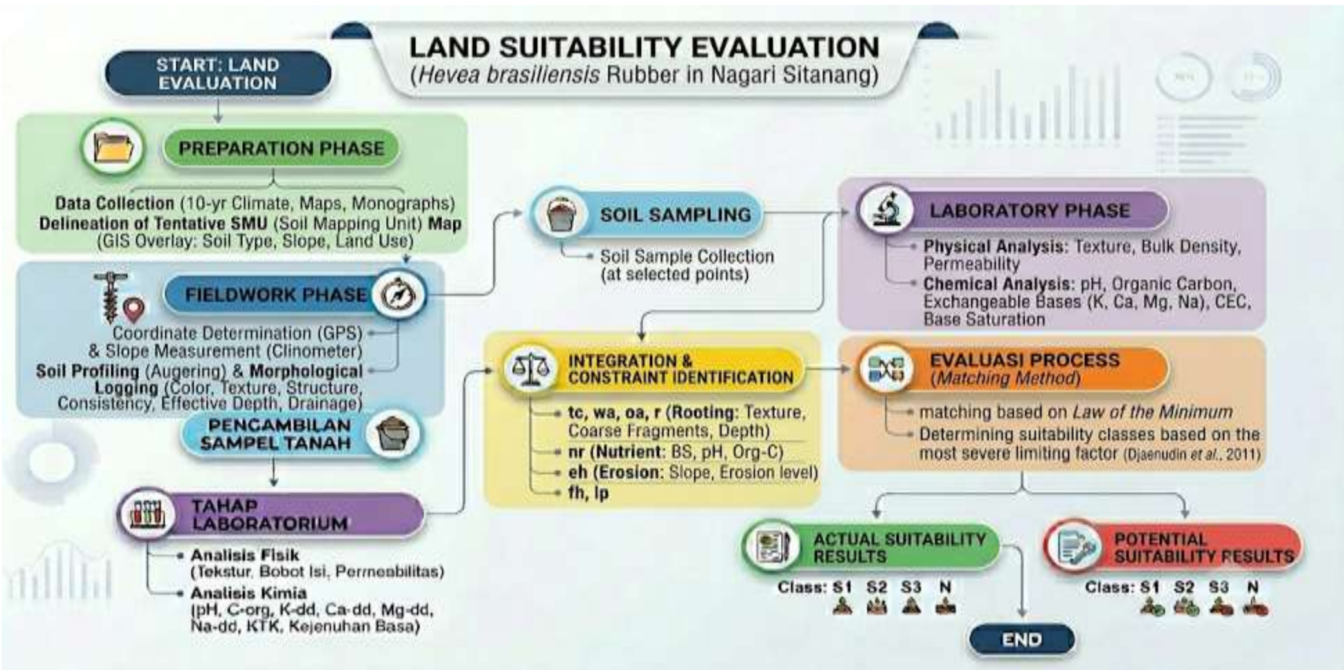

Figure 1. Research scheme

Laboratory procedures were used to analyze physical and chemical soil properties. Physical analyses determined soil texture (pipette method), bulk density (gravimetric method), and permeability (constant head method). Chemical analyses measured soil pH H_2O (1:2.5) and organic carbon (Walkley and Black method). The team extracted exchangeable bases (K, Ca, Mg, Na) and measured the cation exchange capacity (CEC) using 1 N NH_4OAc at pH 7. They calculated base saturation as the ratio of total exchangeable bases to CEC. Evaluated land characteristics encompassed temperature regime (tc), water availability (wa; rainfall), oxygen availability (oa; drainage), and rooting conditions (r; soil texture, coarse fragments, effective depth). The assessment also included nutrient retention (nr; base saturation, pH H_2O, organic carbon), erosion hazard (eh; slope and erosion level), flood hazard (fh), and land preparation requirements (lp; surface rocks and outcrops).

Result and Discussion

Land Characteristics of Nagari Sitanang

Field observations and laboratory analyses of four land units in Nagari Sitanang, namely land units A, B, C, and D, revealed systematic variation in soil characteristics along the slope gradient (Table 2). Increasing slope was associated with a decline in soil organic carbon content. Land unit A, located on a 0 to 8% slope, had the highest organic carbon content at 4.01%, whereas land unit D, located on a slope of more than 25%, had the lowest value at 0.52%. This pattern represents an 87.03% decrease in organic carbon from land unit A to land unit D. This topographic pattern was also reflected in soil physical properties. The coarse fraction increased markedly in land unit D, reaching 55%, indicating greater physical constraints than those found in the other land units. These results suggest that slope gradient strongly affects organic matter accumulation and soil physical condition. Steeper slopes tend to accelerate surface runoff, increase erosion risk, and reduce the capacity of soil to retain organic matter.

Table 1. Land Suitability Criteria for Rubber Cultivation**

Land Characteristics	Suitability Classes			
	S1	S2	S3	N
Temperature regime (tc)				
Mean annual temperature (oC)	26 - 30 oC	30 – 34 oC	-	>34oC
		24 – 36oC	22 – 24 oC	<22oC
Water availability (wa)				
Mean annual rainfall (mm year^{-1})	2500 – 3000	2000 – 2500	1500 – 2000	<1500
		3000 – 3500	3500 – 4000	>4000
Oxygen availability (Oa) Drainage class	Good	Moderate	Somewhat poorly drained; poorly drained	Very poorly drained; excessively drained
Rooting medium (rc)				
Soil texture	Fine; moderately fine; medium	-	Moderately coarse	Coarse
Coarse fraction (%)	<15	15 – 35	35 – 60	>60
Soil depth (cm)	>100	75 – 100	50 – 75	<50
Nutrient retention (nr)				
Base saturation (%)	<35	35 – 50	>50	
Soil pH H_2O	5,0 – 6,0	6,0 – 6,5	>6,5	
		4,5 – 5,0		
Organik carbon (%)	>0,8	<0,8	<4,5	
Erosion hazard(eh)				
Slope (%)	<8	8 – 16	16 – 30	>30
Erosion hazard level (eh)	Very Low	Low to moderate	Severe	Very heavy
Flood hazard (fh)				
Flooding	F0	-	F1	>F1
Land preparation (lp)				
Surface rock (%)	<5%	5 – 15	15 – 40	>40
Rock outcrop (%)	<5%	5 – 15	15 – 25	>25

Source : **(Ritung et al., 2007)

Deng et al. (2021) stated that soil conservation practices are essential on land with high erosion risk because they can significantly reduce runoff and sediment loss on sloping terrain. In line with this, Sappe et al. (2022) identified slope as a key parameter in agricultural land suitability assessment. This slope-related pattern is particularly relevant to rubber-based land evaluation, as Sun et al. (2025) emphasized that soil quality in rubber plantations is strongly influenced by the combined effects of climatic and topographic factors. Therefore, spatial characterization is a critical basis for land suitability evaluation.

Climatic Characteristics

The climatic conditions across the four land units were relatively uniform, as they are located within the same agroclimatic zone. The study area was characterized by a mean annual temperature of 22°C and mean annual rainfall of 2,786 mm year^{-1}. The recorded rainfall falls within the optimal range for rubber cultivation, which is 2,500 to 3,000 mm year^{-1}. This indicates that water availability does not constitute a limiting factor for rubber growth in the study area.

In contrast, the mean annual temperature of 22°C was suboptimal compared with the ideal range of 24 to

28°C. Such conditions may slow vegetative growth and reduce latex flow during cooler periods (Hazir et al., 2020). Sahuri (2024) also reported that climatic factors and water availability affect latex yield, with correlation coefficients between latex yield and rainfall, soil water content, and evapotranspiration of 0.36, 0.42, and 0.52, respectively.

Rooting Medium Characteristics

Rooting medium characteristics in the study area were primarily determined by soil texture, effective soil depth, coarse fraction, and drainage. All four land units were characterized by medium-textured soils. Land units A and C had silt loam textures, whereas land units B and D had loam textures. These textural classes generally favor rubber growth because they provide better water and nutrient retention than sandy soils. According to Djaenudin et al. (2011), medium-textured soils are suitable for rubber root development because they maintain a balance between aeration and water retention.

Effective soil depth also supported root development across the study area. Land units A and B had depths greater than 100 cm, while land units C and D exceeded 90 cm. These values indicate that effective soil depth imposed only a minor constraint on rubber cultivation. As a perennial crop, rubber requires sufficient soil volume to develop a deep root system. However, favorable soil depth should be assessed in relation to other limiting properties, particularly coarse fraction, soil pH, and organic matter content.

The coarse fraction generally increased with slope gradient, from 21.3% in land unit A and 29.2% in land unit B to 24.0% in land unit C and 55.0% in land unit D (Table 2). The value recorded in land unit D approached a severe limiting threshold, indicating the accumulation of rock fragments in the upper soil layer as finer particles were removed by erosion on steep slopes. This condition may restrict root development by reducing the volume of fine soil available for root penetration. Consequently, the soil capacity to store water and nutrients may also decrease. A high coarse fraction can further reduce root-soil contact, thereby lowering nutrient uptake efficiency.

This mechanism is consistent with the findings of Xu et al. (2025), who reported that slope was a dominant factor controlling erosion in rubber plantations in the Lancang-Mekong River Basin, where rubber expansion on steep slopes increased soil loss by up to sixfold. A similar pattern was also reported by Multazam (2023) in smallholder rubber plantations. However, effective soil depth greater than 90 cm across all land units in the present study still met the growth requirements for rubber and therefore did not constitute a limiting factor for plantation development.

Table 2. Characteristics of Hilly Land in Nagari Sitanang, Lareh Sago Halaban Subdistrict

Land characteristics	Land unit			
	A	B	C	D
Temperature regime (tc)				
Mean annual temperature (°C)*	22oC	22oC	22oC	22oC
Water availability (wa)				
Mean annual rainfall (mm year⁻)*	2.786	2.786	2.786	2.786
Oxygen availability (Oa)				
Drainage class	Good	Good	Good	Good
Rooting medium (rc)				
Soil texture	Silt loam (medium)	Loam (medium)	Silt loam (medium)	Loam (medium)
Coarse fraction (%)	21.3%	29.2%	24%	55%
Effective soil dept (cm)	>100 cm	>100 cm	>90 cm	>90 cm
Nutrient retention (nr)				
Base saturation (%)	4.03%	11.1%	5.28%	6.76%
Soil pH H2O	3.95	4.70	4.43	4.50
Soil organic carbon (%)	4.01%	3.10%	2.17%	0.52%
Erosion hazard (eh)				
Slope (%)	0 – 8%	8 – 15%	15 – 25%	>25%
Erosion hazard level (eh)	Very low	Low	Moderate	Severe
Flood hazard (fh)				
Flooding	F0	F0	F0	F0
Land preparation (lp)				
Surface rock (%)	<5%	<5%	<5%	<5%
Rock outcrop (%)	<5%	<5%	<5%	<5%

Source:*(Yanti et al., 2022)

Drainage was classified as good in all land units, indicating adequate soil aeration and no waterlogging constraints. Good drainage facilitates gas exchange between the soil and the atmosphere, thereby maintaining O_2 availability in the root zone (Ben-Noah & Friedman, 2018). Under waterlogged conditions, soil pores become saturated with water, which restricts gas diffusion and reduces oxygen supply for root respiration (Pan et al., 2021). Therefore, drainage was not a limiting factor for rubber root development in the study area.

Nutrient Retention

Nutrient retention conditions were generally unfavorable across all land units. Base saturation ranged from 4.03 to 11.10%, indicating very low levels according to general soil fertility criteria. These values suggest limited reserves of basic cations in the soil, which may restrict the availability of essential nutrients such as Ca, Mg, K, and Na. Soil reaction ranged from strongly acidic to acidic, with pH H_2O values between 3.95 and 4.70.This condition is consistent with the findings of Puspita et al. (2024), who reported that base saturation in the soil of Politeknik Pertanian Negeri Payakumbuh Campus 2 in Nagari Sitanang ranged from 2.33 to 11.10%. In rubber cultivation, acidic soil conditions combined with low base saturation may increase the risk of Al and Fe toxicity, reduce phosphorus availability through fixation, and suppress the activity of phosphate-solubilizing microorganisms. These processes can ultimately limit nutrient uptake by rubber plants (Zou et al., 2021; Sun et al., 2025).

Soil organic carbon exhibited the most pronounced gradient, decreasing from 4.01% in land unit A to 0.52% in land unit D, which represents an almost eightfold decline along the slope gradient. The low organic carbon content in land unit D indicates a reduced capacity to retain nutrients and water. Therefore, if this land unit is used for cultivation, sufficient organic matter inputs are required. Recommended management practices include compost application, well-decomposed manure, organic mulching, cover crop establishment, and the return of plant biomass to the soil.

This marked decline can be attributed to two interrelated mechanisms. First, surface erosion removes organic-rich topsoil from sloping land (Sun et al., 2025). Second, splash erosion in rubber monoculture systems accelerates soil aggregate detachment and intensifies water erosion (Zhu et al., 2023). Zou et al. (2021) further showed that rubber monoculture reduced the soil quality index by 15.50%, with nutrient losses reaching 18.90% compared with natural conditions. These findings support the interpretation that low soil fertility in the steeper land units of Nagari Sitanang is closely associated with erosion-induced organic matter and nutrient depletion.

Erosion Hazard

Erosion hazard on the hilly land of Nagari Sitanang increased with slope gradient, as slope directly affects surface runoff velocity and soil loss on sloping agricultural land (Shanshan et al., 2018). Erosion was the most dominant limiting factor and exhibited a clear topographic pattern: very low in land unit A with slopes of 0 to 8%, low in land unit B with slopes of 8 to 15%, moderate in land unit C with slopes of 15 to 25%, and severe in land unit D with slopes greater than 25%.

This increasing erosion hazard was associated with a decline in soil organic carbon content (Table 2), since erosion commonly removes organic-rich topsoil (Dewi et al., 2020; Rugendo et al., 2023). The role of erosion as a major driver of soil fertility degradation on hilly land has been widely reported in tropical rubber plantation systems (Zhu et al., 2023; Sun et al., 2025; Xu et al., 2025). In land unit D, severe erosion represents a major constraint that is difficult to overcome without intensive soil conservation measures. Effective practices for sloping rubber plantations include bench terracing, legume cover crop establishment, particularly Mucuna bracteata, infiltration pits, and rubber agroforestry systems. These practices have been reported to reduce throughfall kinetic energy by 34 to 76% and splash mass by 86 to 97% compared with monoculture systems (Zhu et al., 2023; Hazir et al., 2020).

Flood Hazard and Land Preparation

Flood hazard and land preparation conditions were not limiting factors in any of the four land units. All units were classified as F0, indicating the absence of flooding, while surface rock and rock outcrop were both less than 5%. Good drainage reduces the likelihood of excess water accumulation in the root zone, thereby supporting favorable soil aeration conditions for rubber growth (Purwanto et al., 2023; Ibol, 2023). The low proportions of surface rock and rock outcrop indicate minimal mechanical constraints for land clearing, tillage, planting hole preparation, and crop maintenance (Suheri et al., 2018; Mujiyo et al., 2025). From a land management perspective, these conditions are favorable because they do not require additional costs for drainage improvement or rock removal during the land-clearing stage.

Land Suitability Classes for Rubber Cultivation

The actual land suitability assessment, conducted using the matching method, classified the four land units in Nagari Sitanang into generally unfavorable categories for rubber development (Table 3). Land units A, B, and C were classified as marginally suitable (S3), whereas land unit D was classified as not suitable (N). None of the evaluated units reached the highly suitable (S1) or moderately suitable (S2) classes, indicating that rubber cultivation in the study area is constrained by substantial land-related limitations.

Land unit A was classified as S3-tc,nr, with mean annual temperature of 22°C (tc) and strongly acidic soil pH H_2O of 3.95 (nr) as the main limiting factors. Land unit B showed a slightly better suitability status and was classified as S3-tc, with temperature as the only dominant constraint. In this unit, soil pH H_2O of 4.70 corresponded to the S2 class, while base saturation met the S1 criterion. Land unit C was classified as S3-tc,nr,eh due to the combined effects of temperature (tc), soil pH H_2O of 4.43 (nr), and slope of 15 to 25%, which corresponded to the S3 class for erosion hazard (eh). Land unit D was classified as N-eh because its slope of more than 25% exceeded the marginal suitability threshold for rubber cultivation. Therefore, under actual conditions, this unit is not recommended for rubber development without extensive landscape modification.

Table 3. Potential Land Suitability for Rubber Cultivation in Nagari Sitanang, Lareh Sago Halaban Subdistrict

Land characteristics	Land Unit			
	A	B	C	D
Temperature regime (tc)				
Mean annual temperature (°C)*	S3(-)	S3(-)	S3(-)	S3(-)
Water availability (wa)				
Mean annual rainfall (mm year^{-1})*	S1	S1	S1	S1
Oxygen availability (Oa)				
Drainage class	S1	S1	S1	S1
Rooting medium (rc)				
Soil texture	S1	S1	S1	S1
Coarse fraction (%)	S2(-)	S2(-)	S2(-)	S3(-)
Effective soil depth (cm)	S1	S1	S2(-)	S2(-)
Nutrient retention (nr)				
Base saturation (%)	S1	S1	S1	S1
Soil pH H_2O	S1(++)	S1(+)	S1(++)	S1(+)
Soil organic carbon (%)	S1	S1	S1	S1(+)
Erosion hazard (eh)				
Slope (%)	S1	S2(-)	S3(-)	N(-)
Erosion hazard level (eh)	S1	S1(+)	S1(+)	S3(-)
Flood hazard (fh)				
Flooding	S1	S1	S1	S1
Land preparation (lp)				
Surface rock (%)	S1	S1	S1	S1
Rock outcrop (%)	S1	S1	S1	S1

Notes: (-) Improvement is not feasible; (+) Moderate improvement can raise the suitability class by one level; (++) High-input improvement can raise the suitability class by two levels.

These findings are consistent with those of Nurkhairani et al. (2025) in Padang Sago Subdistrict, Padang Pariaman Regency, who reported that unsuitable to marginally suitable classes dominated rubber land suitability on hilly terrain in West Sumatra, covering 55.29% of the assessed area. Comparable constraints were also identified by Harahap et al. (2020) in Pakpak Bharat, where soil pH and erosion hazard were the main limiting factors for rubber cultivation on other land-use areas. Temperature was a limiting factor across all land units, reflecting the relatively high elevation of the study area in the hilly landscape of Mount Sago. This condition reduced the mean air temperature below the optimal range of 24 to 28°C for rubber growth (Hazir et al., 2020). Because temperature is largely controlled by elevation and cannot be modified through agronomic intervention, it represents a permanent climatic constraint (Table 3). Under suboptimal temperature conditions, superior rubber clones may still grow, but they tend to require a longer immature period and produce lower latex yields. Therefore, the selection of clones tolerant to lower temperature conditions is a reasonable adaptation strategy.

Potential Land Suitability Classes for Rubber Cultivation

Table 3 presents the potential land suitability classes using three marker notations: (++) for highly rectifiable limitations, (+) for limitations manageable via agronomic or conservation inputs, and (−) for unrectifiable constraints. In land units A, B, and C, the nutrient retention (nr) factor shows a highly promising response to amelioration. Liming via dolomite or $CaCO_3$ elevates soil pH H_2O from classes S2 or S3 to S1. This treatment simultaneously increases base saturation and suppresses Al-Fe toxicity that damages rubber roots (Multazam, 2023; Zou et al., 2021). Sriubon et al. (2025) reinforced this finding, confirming that highly acidic rubber plantation soils require precise lime or dolomite applications. This intervention effectively increases soil pH and improves the availability of essential nutrients.

Soil organic carbon in land unit C (2.17%) and land unit D (0.52%) can be improved to the S1 category through organic fertilizer application, in situ mulching with rubber litter, or the introduction of legume cover crops such as Mucunabracteata. Zou et al. (2021) reported that the introduction of the legume cover crop D. *cochinchinensis* in rubber plantations increased the soil quality index of tropical rubber plantations by up to 33% compared with conventional monoculture. Syofiani et al. (2026) report that the application of organic fertilizer increases soil organic carbon content. Joseph et al. (2024) corroborate this finding. They identify sustainable organic matter management as the primary driver of improvements in soil fertility parameters. This continuous application also maintains stable organic carbon storage in long-term rubber plantations.

However, several rooting medium constraints are inherent soil properties and are difficult to modify economically. The high coarse fraction in land unit D (55%) and the effective soil depth of 90 cm in land units C and D limit the potential improvement of these units, even after soil pH and organic carbon have been improved. Erosion hazard in land units B and C can be reduced by one suitability level through bench terracing, infiltration pits, and cover crop establishment. This finding is consistent with Zhu et al. (2023), who reported that rubber agroforestry systems combined with cover crops reduced splash erosion by 86 to 97% compared with monoculture systems.

Topographic constraints cannot be substantially modified through agronomic management. Therefore, land unit C remained in the S3 class due to slope-related erosion hazard (eh), while land unit D remained in the N class because slopes greater than 25% exceed the suitability threshold for rubber cultivation. Xu et al. (2025) identified slope as a dominant factor controlling erosion in large-scale rubber plantations. This permanent limitation explains why the potential suitability class of land unit D did not improve from N, despite the possibility of improving other soil properties. Fitria et al. (2021) demonstrate that steep slopes significantly degrade the capacity of soil to retain nutrient stocks, specifically organic carbon and nitrogen. This degradation occurs due to accelerated surface runoff. Expanding rubber plantations on extreme slopes without adequate understory cover triggers severe soil detachment and surface erosion. Neyret et al. (2020) prove that these erosion rates are substantially higher than those under other land cover types. These findings confirm that lands with slopes exceeding 25% are highly unsuitable for commercial rubber cultivation.

The final potential land suitability classes were S2-tc for land unit A, S2-tc for land unit B, S3-tc,eh for land unit C, and N-eh for land unit D. In land units A and B, temperature remained the only limiting factor after soil pH improvement. Land unit C remained constrained by slope, while land unit D remained unsuitable due to steep slopes exceeding 25%.Sidabutar et al. (2023) also identified temperature, rainfall, soil texture, and erosion risk as important limiting factors in the evaluation of conservation and plantation crops.

Rubber development in Nagari Sitanang should be prioritized in land units A and B. Recommended management practices include liming to increase soil pH, organic fertilizer application during early planting and periodic maintenance, selection of rubber clones adapted to suboptimal temperature conditions, and establishment of legume cover crops during the immature phase. Cahyo et al. (2022) showed that drought stress is an important constraint in rubber and can be used as a basis for selecting tolerant genotypes. Therefore, rubber development in marginal environments should consider clones with better adaptability to climatic stress. Perron et al. (2024) further reported that legume cover crops between rubber rows reduced runoff by 88% and soil loss by 98% compared with bare soil.

Land unit C may be used for rubber cultivation only with intensive soil conservation measures, including bench terracing, infiltration pits, and strip cropping. Land unit D should be allocated for conservation purposes rather than commercial rubber production. Auliya et al. (2025), stated that land with severe slope limitations should be directed toward more conservative land uses. Overall, land suitability evaluation provides a scientific basis for agricultural commodity planning and for reorganizing smallholder rubber land use in hilly areas of West Sumatra (Romadhoni et al., 2022; Bhumiphan et al., 2023; Luo et al., 2024).

Conclusion

The soil characteristics of the hilly land in Nagari Sitanang varied among land units. Rainfall, drainage, soil texture, effective soil depth, flood hazard, surface rock, and rock outcrop were favorable for rubber cultivation. The main limiting factors were mean annual temperature of 22°C, acidic to strongly acidic soil pH, low base saturation, low soil organic carbon on steep slopes, high coarse fraction in land unit D, and erosion hazard. The actual land suitability classes for rubber cultivation were S3 and N. Land unit A was classified as S3-tc,nr, land unit B as S3-tc, land unit C as S3-tc,nr,eh, and land unit D as N-eh. After land improvement, the potential suitability classes of land units A and B increased to S2-tc, whereas land unit C remained S3-tc,eh and land unit D remained N-eh. The dominant constraints were suboptimal temperature, low nutrient retention, and erosion hazard. Land improvement should include liming, organic fertilizer application, cover crop establishment, infiltration pits or terraces on sloping land, and the use of adaptive rubber clones. Rubber development should be prioritized in land units A and B, implemented with intensive soil conservation measures in land unit C, and avoided in land unit D due to severe slope limitations.

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Conflicts of Interest
The authors declare no conflict of interest.

References

Auliya, I., Widiatmaka, & Syartinilia. (2025). Land Capability Analysis for Sustainable Land Use Planning: A Case Study of Bogor Regency, Indonesia. *Journal of Natural Resources and Environmental Management*, *15*(3). https://doi.org/10.29244/jpsl.15.3.509

Ben-Noah, I., & Friedman, S. P. (2018). Review and Evaluation of Root Respiration and of Natural and Agricultural Processes of Soil Aeration. *Vadose Zone Journal*, *17*(1), 170119. https://doi.org/10.2136/vzj2017.06.0119

Bhumiphan, N., Nontapon, J., Kaewplang, S., Srihanu, N., & Koedsin, W. (2023). Estimation of Rubber Yield Using Sentinel-2 Satellite Data. *Sustainability, 15(9), 7223.* https://doi.org/10.3390/su15097223

Cahyo, A. N., Murti, R, H., Putra, E, T, S., Oktavia, F., Ismawanto, S., & Montoro, P. (2022). Rubber Genotypes with Contrasting Drought Factor Index Revealed Different Mechanisms for Drought Resistance in Hevea brasiliensis. *Plants, 11*(24). https://doi.org/10.3390/plants11243563

Danniswari, D., Aini, Q., Fitri, R., & Fauzi, R. (2024). Penilaian Potensi Pemanfaatan Lahan sebagai Lanskap Produktif berdasarkan Analisis Kesesuaian Lahan Assessing the Potential Utilization of Land as a Productive Landscape based on Land Suitability Analysis. *Agritrop: Jurnal Ilmu-Ilmu Pertanian*, *22*(2), 81–91. https://doi.org/10.32528/agritrop.v22i2.2358

Deng, C., Zhang, G., Liu, Y., Nie, X., & Li, Z. (2021). International Soil and Water Conservation Research Advantages and disadvantages of terracing: A comprehensive review. *International Soil and Water Conservation Research*, *9*(3), 344–359. https://doi.org/10.1016/j.iswcr.2021.03.002

Dewi, E., Haryanto, R., & Sudirja, R. (2020). Pengaruh Penggunaan Lahan dan Posisi Lereng Kandungan C-Organik dan Beberapa Sifat Fisik Tanah Inceptisols Jatinangor, Jawa Barat: Pengaruh Penggunaan Lahan dan Posisi Lereng Kandungan C-Organik dan Beberapa Sifat Fisik Tanah Inceptisols Jatinangor, Jawa Barat. *AGROSAINSTEK: Jurnal Ilmu Dan Teknologi Pertanian*, *4*(1), 49-53. https://doi.org/10.33019/agrosainstek.v4i1.37

Djaenudin, D., Marwan, H., Subagjo, H., & Hidayat, A. (2011). *Petunjuk Teknis Evaluasi Lahan Untuk Komoditas Pertanian.* Balai Besar Penelitian dan Pengembangan Sumber Daya Lahan Pertanian.

Fitria, A. D., & Kurniawan, S. (2021). Land-use changes and slope positions impact on the degradation of soil functions in nutrient stock within the Kalikungkuk micro watershed, East Java, Indonesia. *Journal Of Degraded And Mining Lands Management*, *8*(2), 2689–2702. https://doi.org/10.15243/jdmlm.2021.082.2689

Harahap, F. S., Walida, H., Rauf, A., Rahmawaty, R., Sidabuke, S. H., & Sitompul, R. (2020). Evaluasi Kesesuaian Lahan Untuk Tanaman Karet Pada Areal Penggunaan Lain. *Warta Perkaretan*, *39*(2), 115–126. Retrieved from https://garuda.kemdiktisaintek.go.id/documents/detail/2423304

Hazir, M. H. M., Kadir, R. A., Gloor, E., & Galbraith, D. (2020). Effect of agroclimatic variability on land suitability for cultivating rubber (Hevea brasiliensis) and growth performance assessment in the tropical rainforest climate of Peninsular Malaysia. *Climate Risk Management*, *27*, 100203. https://doi.org/10.1016/j.crm.2019.100203

Hehakaya, H. F., Siahaya, W. A., & Osok, R. M. (2020). Evaluasi Kesesuaian Lahan Tanaman Jagung dan Kelapa Pada Lahan Praktek Sekolah Pertanian Pembangunan Kota Ambon, Provinsi Maluku. *Jurnal Budidaya Pertanian*, *16*(2), 157–166. https://doi.org/10.30598/jbdp.2020.16.2.157

Ibol, P. M. (2023). Temporal assessment of the effect of flooding vulnerability on agricultural land use in the gambia. *Indonesian Journal of Geography*, *55*(3), 456-462. https://doi.org/10.22146/ijg.85232

Jailani, H. Y., Ningsih, M. S., Oktabriana, G., Rahmah, M., Pertanian, P., & Payakumbuh, N. (2025). Perkembangan produksi komoditas unggulan perkebunan Kabupaten Lima Puluh Kota. *Journal Of Science And Social Research*, *8*(3), 4754–4761. https://doi.org/10.54314/jssr.v8i3.4175

Joseph, J., & Ray, J. G. (2024). A critical analysis of soil fertility parameters of rubber plantations with long-term fertilizer use in the western ghats of south India from a global sustainability perspective. *Journal of Rubber Research*, *27*(3), 459–475. https://doi.org/10.1007/s42464-024-00262-6

Liu, C., Pang, J., Jepsen, M. R., Lü, X., & Tang, J. (2017). Carbon Stocks across a Fifty Year Chronosequence of Rubber Plantations in Tropical China. *Forests*, *8*(6), 209. https://doi.org/10.3390/f8060209

Luo, F., He, L., Chen, Z., He, Z., Bai, W., & Zhao, Y. (2024). Optimizing arable land suitability evaluation using improved suitability functions in the Anning River Basin. *Sci Rep*, *14*, 28886. https://doi.org/10.1038/s41598-024-80302-8.

Mujiyo, H. F., Herawati, A., Cahyono, O., Wahyuni, S., Mutiara, C., & Lanamana, W. (2025). Assessment of Land Suitability in Highly Area of Ende , East Nusa Tenggara, Indonesia, as a Basic Strategy for Growing Coffee (Coffea arabica). *Agrikultura*, *36*(3), 441–458, https://doi.org/10.24198/agrikultura.v36i3.64802

Multazam, Z. (2023). Kajian Nilai pH Tanah pada Berbagai Toposekuen dan Kelas Lereng yang Berbeda pada Lahan Perkebunan Karet Rakyat di Kecamatan Pelepat Ilir, Kabupaten Bungo, Jambi. *Jurnal Riset Rumpun Ilmu Teknik (JURRITEK)*, *2*(2), 179–188. https://doi.org/10.55606/jurritek.v2i2.2709 .

Neyret, M., Robain, H., de Rouw, A., Janeau, J.-L., Durand, T., Kaewthip, J., Trisophon, K., & Valentin, C. (2020). Higher runoff and soil detachment in rubber tree plantations compared to annual cultivation is mitigated by ground cover in steep mountainous Thailand. *CATENA*, *189*, 104472. https://doi.org/10.1016/j.catena.2020.104472

Nguyen, T. T., Do, T. T., Harper, R., Pham, T. T., Linh, T. V. K., Le, T. S., Thanh, L. B., & Giap, N. X. (2020). Soil Health Impacts of Rubber Farming: The Implication of Conversion of Degraded Natural Forests into Monoculture Plantations. *Agriculture* Vol. *10*(8), 357. https://doi.org/10.3390/agriculture10080357

Nurkhairani, P., & Triyatno. (2025). Evaluasi kesesuaian lahan untuk komoditas tanaman karet (*Hevea brasiliensis*) dengan menggunakan fuzzy logic di Kecamatan Padang Sago Kabupaten Padang Pariaman Provinsi Sumatera Barat. *Al-DYAS*, *4*(2), 797-810. https://doi.org/10.58578/aldyas.v4i2.4957.

Pan, J., Sharif, R., Xu, X., & Chen, X. (2021). Mechanisms of Waterlogging Tolerance in Plants: Research Progress and Prospects. *Front. Plant Sci.*, *11*. https://doi.org/10.3389/fpls.2020.627331

Perron, T., Legrand, M., Janeau, J.-L., Manizan, A., Vierling, C., Kouakou, A., Brauman, A., Gay, F., Laclau, J.-P., & Mareschal, L. (2024). Runoff and soil loss are drastically decreased in a rubber plantation combining the spreading of logging residues with a legume cover. *Science of The Total Environment*, *913*, 169335. https://doi.org/10.1016/j.scitotenv.2023.169335

Purwanto, A., Andrasmoro, D., Eviliyanto, E., Rustam, R., & Hairy, M. (2023). Validating the GIS-based Flood Susceptibility Model Using Synthetic Aperture Radar (SAR) Data in Sengah Temila Watershed , Landak Regency, Indonesia. *Forum Geografi*, *36*(2), 185–201. https://doi.org/10.23917/forgeo.v36i2.16368

Puspita, D., Syofiani, R., Suhadi, S., Sardina, A., Suryadi, I., & Amir, S. (2024). Evaluasi Kesuburan Tanah Di Lahan Kampus 2 Politeknik Pertanian Negeri Payakumbuh, Nagari Sitanang, Sumatera Barat, Indonesia. *Jurnal Agrium*, *21*(4), 293–300. https://doi.org/10.29103/agrium.v21i4.19581

Ritung, S., Agus, F., & Hidayat, H. (2007). *Land suitability evaluation with a case map of Aceh Barat District*. Retrieved from https://www.cifor-icraf.org/publications/downloads/Publications/PDFS/MN15224.pdf.

Romadhoni, S., Hermiyanto, B., Bowo, C., Budiman, S. A., & Ainunisa, I. (2022). Evaluasi kesesuaian lahan dan rekomendasi penggunaanya untuk komoditas pertanian di Perusahaan Daerah Perkebunan Banongan Kabupaten Situbondo. *Jurnal Tanah Dan Iklim*, *46*(1), 23–36 https://doi.org/10.21082/jti.v46n1.2022.23-36.

Rugendo, M. K., Gichimu, B. M., Mugwe, J. N., Mucheru-muna, M., & Mugendi, D. N. (2023). Surface runoff and soil erosion from Nitisols and Ferralsols as influenced by different soil organic carbon levels under simulated rainfall conditions. *Heliyon*, *9*(7), e17684. https://doi.org/10.1016/j.heliyon.2023.e17684

Sahuri. (2024). Climate Influences on Latex Yield in South Sumatra , Indonesia. *Agromet*, *38*(1), 13–18. https://doi.org/10.29244/j.agromet.38.1.13-18

Sappe, N. J., Baja, S., Neswati, R., & Rukmana, D. (2022). Land suitability assessment for agricultural crops in Enrekang, Indonesia: combination of principal component analysis and fuzzy methods. *SAINS*

TANAH - Journal of Soil Science and Agroclimatology, *19*(2), 165–179. https://doi.org/10.20961/stjssa.v19i2.61973.

Shanshan, W., Baoyang, S., Chaodong, L., Zhanbin, L., & Bo, M. (2018). Runoff and Soil Erosion on Slope Cropland: A Review. *Journal of Resources and Ecology*, *9*(5), 461–470. https://doi.org/10.5814/j.issn.1674-764x.2018.05.002

Sidabutar, F., Trigunasih, N. M., & Sumarniasih, M. S. (2023). Evaluasi Kesesuaian Lahan untuk Pengembangan Tanaman Konservasi dan Perkebunan di DAS Unda, Provinsi Bali, Indonesia. *Agro Bali: Agricultural Journal*, *6*(3), 852–859. https://doi.org/10.37637/ab.v6i3.1277

Sriubon, S., Wongcharoen, A., Meetha, S., & Isarangkool Na Ayutthaya, S. (2025). Nutrient Variables Associated with Tapping Panel Dryness and Necrosis Syndromes in Rubber Tree Clones RRIM600 and RRIT251. *Forests*, *16*(9), 1477. https://doi.org/10.3390/f16091477

Suheri, N. A., Mujiyo, & Widijanto, H. (2018). Land Suitability Evaluation for Upland Rice in Tirtomoyo District, Wonogiri Regency, Indonesia. *Journal of Soil Science and Agroclimatology*, *15*(1), 46–53. https://doi.org/10.15608/stjssa.v15i1.860

Sun, R., Yang, C., Wu, Z., Zhao, L., Lan, G., & Fraedrich, K. (2025). Soil Quality Variation and Its Driving Factors in Rubber Plantations of Tropical China. *European Journal of Soil Science*, *76*(5), e70179. https://doi.org/10.1111/ejss.70179

Syofiani, R., & Oktabriana, G. (2026). Efektivitas berbagai dosis vermikompos terhadap pertumbuhan bibit kakao *(Theobroma cacao L.)*. *Dinamika Pertanian, 42(1),* 54-60 https://doi.org/10.25299/dp.2026.vol42(1).28068

Xu, H., Pham, T. D., Wu, Q., Chai, P., Lu, D., Li, D., & Chen, Y. (2025). Rubber Plantation Expansion Leads to Increase in Soil Erosion in the Middle Lancang-Mekong River Basin During the Period 2003–2022. *Remote Sensing*, *17*(13), 2220. https://doi.org/10.3390/rs17132220

Yanti, D., Irsyad, F., & Stiyanto, E. (2022). *Laporan akhir penyusunan master plan dan action plan pengembangan kawasan jagung Kabupaten Lima Puluh Kota*. Dinas Tanaman Pangan, Hortikultura dan Perkebunan Kabupaten Lima Puluh Kota & LPPM Universitas Andalas. Retrieved from https://distanhortbun.limapuluhkotakab.go.id/downloadppid/Action_Plan_Pengembangan_Jagung_compressed.pdf

Zhu, X., Yuan, X., Lu, E., Yang, B., Wang, H., Du, Y., Kumar, A., & Liu, W. (2023). Soil splash erosion: An overlooked issue for sustainable rubber plantation in the tropical region of China. *International Soil and Water Conservation Research*, *11*(1), 30–42. https://doi.org/10.1016/j.iswcr.2022.05.005

Zou, X., Zhu, X., Zhu, P., Singh, A. K., Zakari, S., Yang, B., Chen, C., & Liu, W. (2021). Soil quality assessment of different Hevea brasiliensis plantations in tropical China. *Journal of Environmental Management*, *285*, 112147. https://doi.org/10.1016/j.jenvman.2021.112147