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Original Research Article

Land Suitability Assessment for Cocoa (*Theobroma cacao* L.) Production in Selected Soils of the *Mambilla* Plateau, Northeast Nigeria

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Abstract

The *Mambilla* Plateau in Taraba State, Nigeria, possesses significant agricultural potential, yet its suitability for cocoa production remains largely unexamined. This study assessed the Plateau's soils for cocoa cultivation, with implications for income generation, employment, and agro-industrial development. Twelve soil profile pits were established across the area, described, and sampled by paedogenetic horizons. Analyses followed the FAO Land Suitability Evaluation Protocol. Most soils were deep (>150 cm), except for profile pit 03, which was shallow. Textures ranged from sandy clay loam to clay loam, with moderately to slightly acidic pH (5.61–6.18). Organic carbon was generally low (0.07–0.26 %), while cation exchange capacity (7.00–20.02 cmol kg^{-1}) and base saturation percentage (61.35–80.02 %) were moderate to high, aligning with cocoa nutrient demands. Climate and topography were optimal; however, drainage varied, with three profiles poorly drained. Actual suitability classes were largely marginal (S3), with fertility and texture as limiting factors, and drainage issues reducing suitability to N1 in some areas. Nonetheless, potential ratings improved substantially to S2 or S1 with targeted management, including organic matter incorporation, non-acidifying fertilisers, and drainage enhancement. Productivity index values ranged from 26.52 (S3) to 75.00 (S1), reflecting this potential. These findings highlight not only current limitations but also the transformative potential of well-informed, site-specific agricultural policy and practice in the *Mambilla* region. Supporting interventions such as soil-specific recommendations, subsidized inputs, and farmer training could operationalize these findings. Hence, incorporating geospatial tools and socioeconomic variables like land access and farmer capacity in future works would enhance relevance and adoption.

Keywords: Cocoa; Land evaluation; *Mambilla* Plateau; NE Nigeria; Soil fertility; Soil amendments

INTRODUCTION

Cocoa is a vital cash crop that significantly contributes to wealth creation, raw materials, employment, and economic growth in producing countries. It is a leading export crop worldwide, with Africa alone recording a total export of 4,645,000 tons during the 2022/2023 growing season (International Cocoa Organization, 2023). The crop is predominantly grown in humid tropical regions such as Central and South America, Asia, and Africa. In West Africa, commercial production of cocoa became economically crucial in Nigeria from the 1870s, owing to the favourable humid tropical conditions that support its cultivation (Osei-Gyabaah et al., 2023).

As a capital-intensive crop, cocoa production requires land suitability assessment to ensure sustainable and optimal productivity. Land suitability evaluation measures how well land supports specific agricultural uses and provides insights into resource limitations, potentials, and guidance for agricultural planning (FAO, 1976). Soil suitability assessments aid in identifying constraints to productivity, which are necessary for adopting relevant management practices to improve yields (Rabia, 2012). The *Mambilla* Plateau, despite its potential for agricultural production, faces challenges related to soil variability, erosion, and nutrient deficiencies. The lack of detailed land suitability assessments for cocoa, a high-value crop with the potential to improve livelihoods in the region, exacerbates these challenges. Without proper land evaluation, farmers may unknowingly cultivate cocoa on unsuitable land, leading to crop failure, wasted resources, and economic hardship. This also contributes to unsustainable land management practices and environmental degradation, ultimately limiting the region's economic development.

Research on the suitable cultivation of cocoa has increasingly emphasized climate and soil influence on its productivity. Several methods have been employed to evaluate land suitability for cocoa cultivation in Nigeria. These individual methods have highlighted different constraints to its sustainable cultivation. For instance, Rojas-Briceño et al. (2022) identified climate and low soil fertility as key constraints limiting cocoa suitability in the tropics. Similarly, studies in *Ife* Central, *Osun* State (Ayorinde et al., 2015), and tropical regions (Kongor et al., 2024), highlighted soil texture and nutrient retention as key limitations.

Among the methods used for land suitability evaluation (LSE), the FAO (1976) framework is particularly popular due to its direct approach and tested accuracy in suitability assessments. This approach considers the capacity of largely homogeneous soil entities representable by pedons to provide nutrition requirements for specific crops (Adegbenro et al., 2023). For example, Olasoji et al. (2022) applied this framework in *Ijaka-Isale*, *Yewa* North, *Ogun* State, Nigeria, reporting marginal and unsuitable land classes for cocoa due to annual temperature and soil fertility limitations.

While previous studies have assessed cocoa suitability in other parts of Nigeria, this research provides the first detailed assessment of the *Mambilla* Plateau, a region with unique pedological characteristics and significant potential for cocoa expansion. This study combines detailed soil property analysis with the FAO (1976) land evaluation framework to identify specific limitations and opportunities for cocoa cultivation in this understudied area. The absence of cocoa-specific suitability information in the region makes the expansion of cultivation a risky venture for farmers, considering that cocoa cultivation is a capital- and labour-intensive enterprise. Drawing from earlier survey work in the area, which reported marked pedogenetic variation across the *Mambilla* soils (Osujieke and Obasi, 2024), we hypothesize that some soils within the Plateau possess characteristics suitable for sustainable cocoa cultivation, driving the study's objective of identifying soil and site limitations governing the spatial potential for sustainable cocoa expansion across the Plateau.

Despite Nigeria producing only about 5.1% of the world's cocoa beans in 2023, placing it among the top global producers, cocoa remains one of its most valuable agricultural export commodities and a major source of rural income (Kehinde et al., 2022; Otekunrin et al., 2025). This paradox of high domestic relevance but modest global competitiveness highlights the need for systematic land evaluations, particularly in potentially suitable regions like the *Mambilla* Plateau. Therefore, this study aims to test the stated hypothesis by assessing the suitability of soils on the *Mambilla* Plateau for cocoa cultivation using the LSE approach, thereby generating empirical data to support decision-making for the expansion of cocoa cultivation in Nigeria.

MATERIALS AND METHODS

Study Location

The *Mambilla* Plateau is situated in Northeastern Nigeria within the Sardauna Local Government Area of *Taraba* State. The area covers approximately 3,765.2 km^2, geographically, spanning through latitudes 6°30′24″ to 7°19′48″ N and longitudes 11°02′42″ to 11°37′12″ E (Figure 1). The region is renowned for its unique high-altitude terrain, with elevations ranging from 1,200 to 1,800 m asl, featuring an area with lower mean temperatures than surrounding lowlands (Chapman and Chapman, 2001). The geology, dominated by Basement Complex rocks (Tijani, 2023), significantly influences soil properties and landscape that afford an intricate combination of land characteristics with visibly diverse capabilities, triggering use-specific investigations.

Climate of the Study Area

The *Mambilla* Plateau exhibits distinct seasonal variations. Between 1994 and 2024, annual average maximum and minimum temperatures were 29.4 °C and 15.5 °C, respectively, typical of highland environments. Peak temperatures occur in February and March, reaching up to 38.1 °C, while cooler conditions

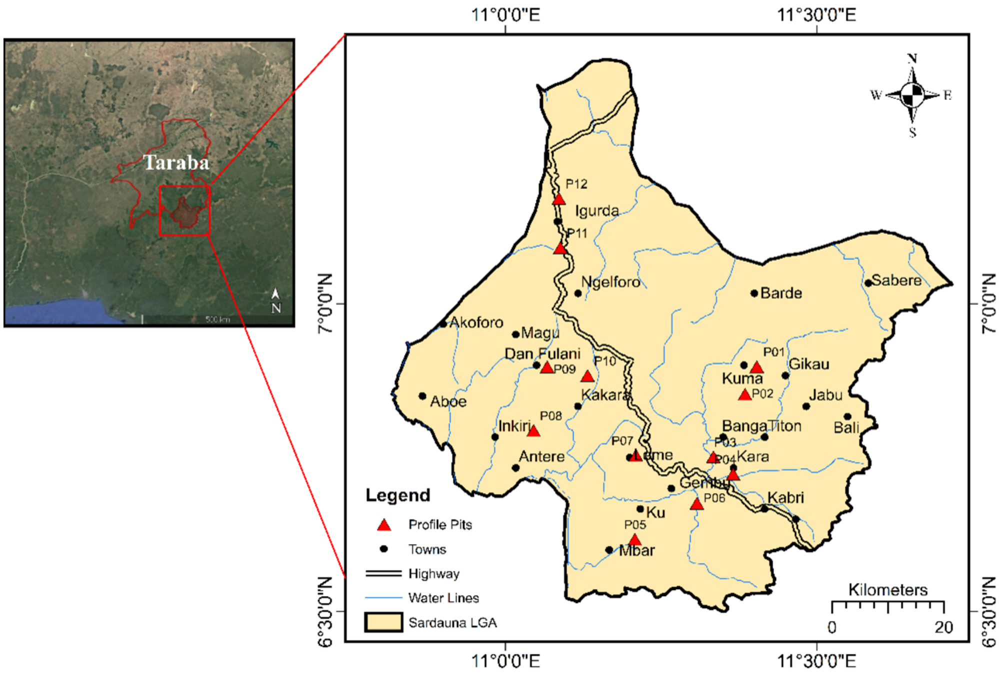

Figure 1. Location of study pedons in *Sardauna* Local Government Area, *Taraba* State, Nigeria.
Source: Map created by the authors using ArcGIS 10.7.2 with administrative boundary data from GADM (version 4.1, 2023; https://gadm.org), river/road data from OpenStreetMap contributors (© OpenStreetMap) and map imagery from Google Earth Pro (version 7.3, Google, 2024).

prevail during the rainy season (June–September), with August recording the lowest average maximum of 26.4 °C (Figure 2).

Annual rainfall averages 1,654.7 mm, with most precipitation between April and October, and a peak in August. The dry season (November–March) is characterised by minimal rainfall. The relative humidity in the area exhibits a distinct pattern mirroring rainfall trend, with peak values (78.9 %) observed between August and September and the lowest (15 %) recorded in December–January. The annual average is approximately 47 %. This climatic pattern provides a favourable moisture regime for cocoa, which requires adequate rainfall during its active growth periods, and a well-defined dry season to reduce disease pressure (Adegbenro et al., 2023).

Field and Laboratory Studies

To test the hypothesis that some soils of the *Mambilla* Plateau are suitable for cocoa cultivation, land units representing major pedological and topographic variations were selected via a reconnaissance survey for detailed characterization and suitability evaluation (FAO, 2006). Following the FAO (2006) guidelines, twelve soil profile pits (2 m × 1.8 m × 2 m) were excavated across the study area using a stratified random sampling approach in which each land unit was first treated as a stratum, and profile locations were then selected at random within each stratum to avoid bias and ensure coverage of the full range of land conditions (Webster and Oliver, 2007). The profile pits were sampled at standard genetic horizon depths, with topsoil (Ap) and subsoil horizons (Bt and Btcv) sampled based on genetic horizon differentiation (USDA, 2017). Samples were air-dried and sieved through a 2 mm mesh before being used for routine analysis following standard laboratory protocols.

Soil pH was measured in a 1:2.5 soil-to-water ratio using a Jenway 3510 pH meter (Thomas, 1996). Exchangeable acidity, bases, and cation exchange capacity (CEC) were determined using the 1N ammonium acetate (NH_4OAc) extraction method at pH 7.0 (McLean, 1982; Thomas, 1982; Sumner and Miller, 1996). In this method, soil samples were leached with 1N NH_4OAc to displace exchangeable cations, followed by filtration and quantification of exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, and Na^+). Calcium and magnesium were determined using a PerkinElmer AAnalyst 400 atomic absorption spectrophotometer (AAS), while potassium and sodium were analysed using a Jenway PFP7 flame photometer. Exchangeable acidity ($H^+ + Al^{3+}$) was extracted using 1N KCl and quantified by titration with 0.01N NaOH. Total carbon and nitrogen contents were analysed by wet digestion (Nelson and Sommers, 1996) and the Kjeldahl method (Bremner and Mulvaney, 1982), respectively. Available phosphorus

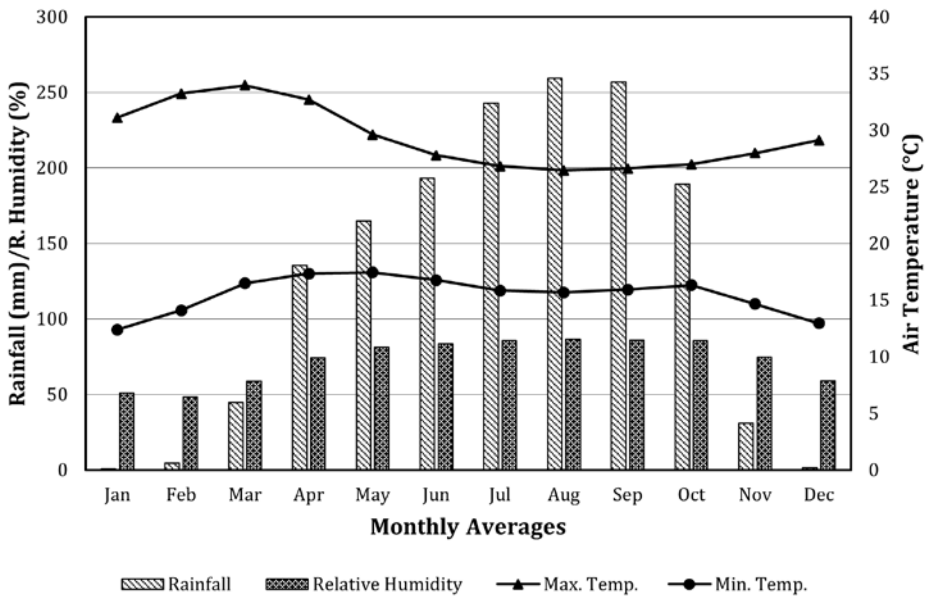

Figure 2. Summary of Monthly Rainfall, Minimum and Maximum Temperatures in the Study Area from 1994–2024. Source: NASA POWER Data Access Viewer (2024)

Table 1. Factor Rating of Land Use Requirements for Cocoa

Land Quality	Units	S1		S2	S3	N1
		100–95	**95–85**	**85–60**	**60–40**	**<40**
A. Climate (c)						
Mean Rainfall	mm yr^{-1}	1,900–1,800	1,800–1,600	1,600–1,400	1,400–1,200	<1,200
		1,900–2,000	2,000–2,500	2,500–3,500	3,500–4,400	>4,400
Mean Temp.	°C	26–25	25–23	23–22	22–21	<21
		26–28	28–29	29–30		>30
Relative Humidity	%	45–55	45–40	40–35	30–35	<30,
		55–60	60–65	65–75	75–85	>85
B. Topography (t)						
Slope	%	0–4	4–8	8–16	16–30	>30
C. Wetness (w)						
Soil drainage Class		WD	WD	MD	ID	PD
D. Soil Physical Characteristics (s)						
Soil texture		SiCL, CL, SiL	L, SC	SCL	LfS, SL	LS, S
Soil depth	cm	>200	200–150	150–100	100–50	<50
E. Fertility (f)						
Organic carbon	%	>2.4	2.4–1.5	1.5–0.8	<0.8	
pH (H_2O)		6.4–6.2	6.2–6.0	6.0–5.5	5.5–5.0	<5.0
		6.4–6.6	6.6–7.0	7.0–7.6	7.6–8.2	>8.2
CEC	cmol kg^{-1}	>24	24–16	10–16	<10	
TEB	cmol kg^{-1}	>6.5	6.5–4	4–2.8	2.8–1.6	<1.6
Base saturation	%	>50	50–35	35–20		<20

Keys: S1 = highly suitable (SI% 100–85), S2 = moderately suitable (SI% 85–60), S3 = marginally suitable (SI% 60–40), N1 = currently not suitable (SI% <40); the numbers are the ranges of suitability index percentages (SI%) assigned to each class. Textures = S – sand, Si – silt, C – clay, L – loam, LfS – fine sand; CEC – cation exchange capacity; TEB – total exchangeable bases; Drainage = WD – well drained, PD – poorly drained, ID – imperfectly drained, MD – moderately drained
Source: Adopted from Sales et al. (2024).

was measured using the Bray I method (Olsen and Sommers, 1982) with a UV-Vis spectrophotometer (SPECORD 210 Plus).

Land Suitability Evaluation (LSE)

Land suitability was assessed for cocoa cultivation, following the FAO (1976) guidelines and parametric methods (Ogunkunle, 1993; Udoh and Ogunkunle, 2012). For the former, suitability classes (highly suitable [S1], moderately suitable [S2], marginally suitable [S3], and currently not suitable [N1]) were assigned based on the most limiting characteristics of each profile against the crop requirements in Table 1, while a suitability index of productivity (IP) was used to assess crop productivity in each unit.

After matching, the IP for each soil unit was calculated using the equation below, with adjustments for potential suitability excluding fertility constraints that are traditionally supplemented for in the tropics.

$$\text{Index of Productivity}\left(\text{IP}\right) = A \times \sqrt{\Pi_{i=4}^{4} \frac{S_i}{100}}$$

Where A is the most compelling factor (i.e. climatic), and Si represents limiting factor ratings for topography, wetness, soil physical properties, and fertility. Classes S1 to N1 correspond to IP values ranging from >74 to <24 (Taghizadeh-Mehrjardi et al., 2020).

RESULTS AND DISCUSSION

Land Quality Indicators in the Study Area

The study assessed climatic conditions, soil physical and chemical properties as key land quality indicators. While climatic factors were largely uniform across the study area, soil properties showed considerable variation (Table 2), suggesting other factors such as topography, geology and land use as potential drivers of soil variation in the area. The variations of soil properties impacted the soil's suitability for cocoa production differently.

Climate (c)

The *Mambilla* Plateau's climate is well-suited for cocoa cultivation, with an annual rainfall of 1650.5 mm, a mean relative humidity of 47%, and mean temperatures ranging between 18 °C and 32 °C (Figure 2). This aligns with cocoa's optimal growth requirements (Sales et al., 2024). The rainfall distribution patterns also support sustainable cocoa production, while the dry spell from November to March remains within acceptable limits (Osei-Gyabaah et al., 2023). High humidity levels are known to promote the *Phytophthora spp.* pathogens which cause black pod disease, but the *Mambilla* Plateau's moderate humidity will control the risk of severe outbreaks (Osei-Gyabaah et al., 2023).

Topography (t) and Wetness (w)

The slope percentage in the study units ranged from 0 to 4%, which is highly suited for cocoa cultivation. Slope is an important factor that may be used to assess risks of soil erosion. Steeper slopes may lead to surface erosion, which can in turn affect soil depth and nutrient retention, which are both vital for growth and development of the crop (Koulouri and Giourga, 2007). Drainage conditions were highly suitable (S1) in eight of the twelve profile pits but were marginally suitable (S3) in four pits (P03, P04, P07, and P11) due to imperfect drainage caused by shallow water tables (Table 3). Proper drainage is essential in promoting healthy cocoa growth, as waterlogged soils can hinder root function and increase susceptibility to bacterial and fungal diseases which impacts both yield and quality. Hence, understanding slope impacts on soil is fundamental for maximizing agricultural yield (Van Asselen and Verburg, 2012).

Soil Physical Characteristics (s)

Soil texture and depth are critical for cocoa cultivation. Four profile pits exhibited highly suitable textures (sandy clay or clay loam), while the others were either moderately or marginally suitable. On the other hand, 91.67% of the pits had sufficient depth to support cocoa production. The impact of soil texture on key soil properties such as moisture and nutrient retention, root growth and biodiversity has long been established (Weil and Brady, 2017). Moderate textured soils with good drainage are ideal for retaining moisture during dry periods, supporting root development and nutrient availability (Sales et al., 2024). Variations in texture and depth may affect water retention and root penetration, critical for cocoa productivity.

Soil Fertility (f)

Soil pH, ranging from 5.61 to 6.18, was slightly to moderately acidic, which aligns with values previously observed in areas with similar rainfall amounts (Oyebiyi et al., 2024). Soil pH plays a crucial role in nutrient availability, with optimal conditions for most crops occurring between 5.5 and 7.5 (Weil and Brady, 2017). The pH levels observed in this study generally fall within this range, making them suitable (S1 to S2) for cocoa production.

The CEC values (7.00–12.33 cmol kg^{-1}) were largely low, except in P03 (20.02 cmol kg^{-1}), which was high (Table 2). This limitation could hinder nutrient

Table 2. Summary of Land Qualities/Characteristics in the Study Area

Pedons	Slope (%)	Soil drainage	Slope Position	Depth (cm)	Soil texture	pH (H_2O)	OC (%)	CEC (cmol kg^{-1})	TEB	BSP (%)
P01: 6°53′52.80″, 11°24′13.90″	0–1	WD	MS	180	SCL	5.79	0.20	8.92	7.06	79.44
P02: 6°51′11.50″, 11°23′06.05″	2–4	WD	MS	160	SC	5.71	0.19	8.84	8.91	78.49
P03: 6°45′05.30″, 11°20′02.70″	1–2	PD	LS	106	SL	6.18	0.15	20.02	7.00	73.86
P04: 6°43′24.40″, 11°21′56.70″	2–4	PD	VB	200	SCL	5.57	0.12	8.00	5.85	76.49
P05: 6°37′03.40″, 11°12′28.10″	2–3	WD	US	200	SL	5.71	0.16	8.00	7.42	79.7
P06: 6°40′34.10″, 11°18′27.40″	0–1	WD	MS	200	CL	5.61	0.07	7.00	5.67	76.97
P07: 6°45′15.10″, 11°12′34.60″	0–2	ID	VB	210	SCL	5.67	0.26	10.00	8.61	80.02
P08: 6°47′39.40″, 11°02′42.10″	0–2	WD	CS	200	SC	5.96	0.14	12.33	6.10	78.56
P09: 6°53′51.80″, 11°04′00.70″	0–1	WD	US	200	SL	5.85	0.18	8.90	5.21	73.18
P10: 6°53′00.80″, 11°07′54.80″	0–1	WD	CS	180	SC	6.14	0.18	10.00	7.46	71.12
P11: 7°05′27.60″, 11°05′17.00″	2–4	ID	LS	200	SCL	5.95	0.20	9.54	6.93	61.35
P12: 7°10′16.10″, 11°05′09.00″	2–4	WD	CS	200	SL	6.07	0.26	8.00	6.44	62.65

Keys: Drainage = WD – well drained, PD – poorly drained, ID – imperfectly drained; Slope position = CS – crest slope, US – upper slope, MS – middle slope, LS – lower slope, VB – valley bottom; Texture = S – sand, C – clay, L – loam; BSP – base saturation percentage; CEC – cation exchange capacity; TEB – total exchangeable bases, OC – organic carbon.
Source: Authors' field survey and laboratory analysis (2024).

retention and amplify the effect of leaching, especially when the rainfall conditions is brought to consideration. Soils with low CEC have reduced nutrient-holding capacity, increasing the likelihood of nutrient leaching, particularly under high-rainfall conditions. This suggests that frequent fertilizer applications may be necessary to sustain adequate nutrient levels. Interestingly, optimal CEC values (S1 and S2) were observed in soils where texture and drainage were limiting factors for cocoa production such as P03, P07, P08 and P10 (Table 2). This trend aligns with Awwal and Maniyunda (2023), who reported a significant correlation between CEC and clay content in soils formed on basement complex rocks. Similarly, Olasoji et al. (2022) attributed low CEC levels in cocoa soils to limited clay and organic matter content.

Despite the low CEC, base saturation was rated highly suitable (S1) across most profile pits, indicating good potential for nutrient availability (Table 2). The consistently high base saturation suggests that the parent material may be inherently rich in weatherable minerals, contributing to maintaining a favourable cation balance (Maniyunda, 2012). Organic carbon levels were generally lower than the suitable limit (0.8%) in all profile pits studied and were hence rated N1 (Table 2). Organic carbon levels in the tropics have generally being reported to be low due to over-depletion by climatic factors (Wells et al., 2022). Similar low OC levels have been reported in cocoa-growing soils of the Iwo series (Adegbenro et al., 2023) and in granitic and gneiss soils of Southwestern Nigeria (Olasoji et al., 2022), where suitability ratings still ranged from S1 to S3. This suggests that despite low OC content, other soil properties such as pH, BS, and CEC can compensate to sustaining cocoa production with appropriate fertility management strategies. Nonetheless, strategic interventions such as organic amendments such as incorporation of compost and biochar, as well as cover cropping may aid to restore soil organic matter levels and enhance long-term soil fertility.

Land Suitability Classes in the Study Area

Climate (c), texture class (s), drainage (w), and fertility (f) were the primary factors influencing cocoa suitability in the study area (Table 32). Most of the profiles were classified as marginally suitable (S3) due to fertility constraints, while some were rated as currently or permanently not suitable (N1 and N2) due to severe limitations such as poor drainage and unfavourable soil structure. However, the potential suitability analysis highlights promising improvements with appropriate soil management interventions.

Based on the actual suitability ratings, six profiles (P01, P02, P05, P06, P08, and P10) were marginally suitable (S3), with IP values ranging from 32.48 to 37.50. Three profiles (P03, P07, and P11) were classified as permanently not suitable (N1), while P04 was currently not suitable (N2), primarily due to limitations in climate, wetness, and soil fertility (Table 3). This suggests that soils located on lower slope to valley bottom positions in the study area were less suited for cocoa cultivation. These results lend support to the initial hypothesis that certain soils of the *Mambilla* Plateau possess favourable characteristics for cocoa cultivation, with topographic and fertility constraints emerging as the main limiting factors. This outcome corroborates earlier pedogenetic

Table 3. Land suitability Class Scores for Cocoa Production in 12 Profile Pits of the *Mambilla* Plateau Based on the FAO (1976) Framework

	Parameter	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12
A	**Climate (c)**												
	Rainfall	S1 (90)	S1 (90)	S1 (90)	S1 (90)	S1 (90)	S1 (90)	S1 (90)	S1 (90)	S1 (90)	S1 (90)	S1 (90)	S1 (90)
	Temperature	S2 (75)	S2 (75)	S2 (75)	S2 (75)	S2 (75)	S2 (75)	S2 (75)	S2 (75)	S2 (75)	S2 (75)	S2 (75)	S2 (75)
	Rel. Humidity	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (100)
B	**Soil Physical Properties (s)**												
	Depth	S1 (90)	S1 (90)	S2 (75)	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (90)	S1 (100)	S1 (100)
	Texture Class	S2 (75)	S1 (90)	S3 (50)	S2 (75)	S3 (50)	S1 (100)	S2 (75)	S1 (90)	S3 (50)	S1 (90)	S2 (75)	S3 (50)
C	**Topography (t)**												
	Slope (%)	S1 (100)	S1 (90)	S1 (100)	S1 (90)	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (90)	S1 (90)
D	**Wetness (w)**												
	Drainage Class	S1 (100)	S1 (100)	N1 (25)	N1 (25)	S1 (100)	S1 (100)	S3 (50)	S1 (100)	S1 (100)	S1 (100)	S3 (50)	S1 (100)
E	**Fertility (f)**												
	OC	N1 (25)	N1 (25)	N1 (25)	N1 (25)	N1 (25)	N1 (25)	N1 (25)	N1 (25)	N1 (25)	N1 (25)	N1 (25)	N1 (25)
	pH	S2 (75)	S2 (75)	S1 (90)	S2 (75)	S2 (75)	S2 (75)	S2 (75)	S2 (75)	S2 (75)	S1 (90)	S2 (75)	S1 (90)
	CEC	S3 (50)	S3 (50)	S1 (90)	S3 (50)	S3 (50)	S3 (50)	S2 (75)	S2 (75)	S3 (50)	S2 (75)	S3 (50)	S3 (50)
	TEB	S1 (100)	S1 (100)	S1 (100)	S1 (90)	S1 (100)	S1 (90)	S1 (100)	S1 (90)	S1 (90)	S1 (100)	S1 (100)	S1 (90)
	BS	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (100)	S1 (100)
	IP (Actual)	32.48	33.75	13.26	15.40	26.52	37.50	22.96	35.58	26.52	35.58	21.79	25.16
	Actual Class	**S3-csf**	**S3-cf**	**N2-cwsf**	**N1-cwsf**	**S3-csf**	**S3-cf**	**N1-csf**	**S3-cf**	**S3-csf**	**S3-cf**	**N1-cswf**	**S3-csf**
	IP (Potential)	64.95	67.50	26.52	30.81	53.03	75.00	45.93	71.15	53.03	71.15	43.57	50.31
	Potential Class	**S2-cs**	**S2-c**	**S3-cws**	**S3-cws**	**S2-cs**	**S1-c**	**S3-cs**	**S2-c**	**S2-cs**	**S2-c**	**S3-csw**	**S2-cs**

Source: Based on field and laboratory data from authors' field survey and laboratory analysis and classification criteria from adopted from Sales et al. (2024).

observations of soil variability on the Plateau (Osujieke and Obasi, 2024) and provides a sound basis for site-specific land management interventions to guide cocoa expansion within the FAO (1976) evaluation framework.

Furthermore, the potential suitability ratings suggest significant improvements with targeted soil fertility management, particularly through organic matter amendments and nutrient supplementation. Profiles P02, P06, P08, and P10 show the potential to improve from S3 to S2, with IP values increasing to between 67.50 and 71.15. Notably, profile P06, which was previously marginally suitable, has the potential to achieve an S1 rating (IP = 75.00) with effective fertility enhancements. Similarly, profiles P01, P05, and P09 exhibit improvements within the S2 category, while P07 and P11 could transition from N1 to S3 if managed appropriately (Table 3).

Although profiles P03, P04, and P07 remain in the S3 category despite potential enhancements (Table 3), their limitations, particularly in drainage and soil texture, indicate the need for more intensive interventions beyond fertility amendments or utilization of these soil units for a use that is more suited to their inherent physical constraints, such as pasture, forestry, or perennial crops with lower drainage and texture sensitivity.

Broader sustainability considerations also emerge from these findings. Improving the suitability of soils for cocoa on the *Mambilla* Plateau is not only a matter of productivity but also of long-term sustainability. Targeted soil management that enhances fertility, drainage, and structure can strengthen climate resilience by buffering cocoa systems against rainfall variability and temperature stress. At the same time, raising marginally suitable soils into higher suitability classes has the potential to improve smallholder livelihoods by stabilizing yields and incomes, reducing the pressure to clear new land, and promoting more sustainable land-use practices (Kehinde et al., 2022). Such linkages between soil suitability, climate resilience, and rural livelihoods position land evaluation studies as critical tools for both local agricultural planning and broader global sustainability goals.

CONCLUSION

The study evaluated soils on the *Mambilla* Plateau for cocoa production, identifying that most soil units were marginally suitable (S3) or moderately suitable (S2), with a few classified as currently or permanently not suitable (N1 and N2). This confirms the hypothesis that portions of the *Mambilla* Plateau are suitable for cocoa cultivation, though suitability varied considerably due to inherent limitations. Climate and topography were generally favourable for cocoa production, while the identified limitations include low CEC, poor drainage, and suboptimal soil texture. These limitations influence nutrient availability, water retention, and root penetration, all of which are critical for cocoa growth.

However, the potential suitability assessment highlights significant opportunities for improvement. Targeted soil management strategies, such as applying non-acidifying fertilizers and incorporating organic matter could elevate over 50% of the land units, especially those located on crest, upper and middle slope positions to higher suitability classes.

While the study was grounded in detailed soil property analysis, integrating spatial variability at broader scales through geospatial modelling would further enhance the applicability of these findings across the *Mambilla* Plateau. Expanding future assessments to include high-resolution spatial tools and wider topsoil sampling can provide more generalized and scalable recommendations. In addition, incorporating yield data, crop performance trials, as well as linking empirical production functions of soil and climate attributes to actual cocoa output would strengthen the practical relevance of land suitability assessments. Also, embedding socioeconomic dimensions such as farmer capacity and land accessibility in future studies would likely facilitate the adoption of these technical recommendations.

CONFLICT OF INTEREST

The authors declare no conflicts of interest concerning the research, authorship, and publication of this article.

ETHICAL COMPLIANCE

The authors have followed ethical standards in conducting the research and preparing the manuscript.

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