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Soil Characteristics, Taxonomy and land suitability of a lateritic Mantle for rain-fed maize (Zea mays) Agriculture in the Cameroon Western Highlands

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Numerous farmers experience a knowledge gap between the cultivation capabilities of land units (LU) responsible for spatial yield variability. This research aims to characterize and evaluate a lateritic toposequence for rain-fed maize in Western Cameroon. Five soil profiles dug along an N-S transect enabled assessing land suitability for maize using the FAO method. The main results revealed that LU N° 1 (Summit) and 4 (Footslope) are currently marginal (S3) for maize cultivation, caused by climatic and soil physical constraints. LU N° 2 (basin with outflow), 3 (Backslope), and 5 (endorheic basin) are unsuitable (N2 and N), due to poor root zone aeration and unsuitable topography. Improved management strategies could allow for the reclassification of land use (LU) categories as follows: Unit 1, currently classified as Rhodic Eutric Nitisol (Ferric), could be deemed moderately suitable. Units 2, 3, and 5, which are Gleyic Stagnosol, Pisoplinthic Plinthosol, and Stagnic Gleysol, respectively, could be classified as marginally suitable. Finally, Unit 4, identified as Eutric Nitisol, could be reclassified as suitable. For potential yields, 47% is marginal (5.13 t/ha), 34% is suitable (0.97-2.27 t/ha) and 18% is moderate (0-1.95 t/ha). Comparing actual and potential yields, under low and medium input farming, yields with low input increase from 0.9 t/ha (actual suitability) to 4 t/ha (potential suitability), while medium levels increase from 2.27 t/ha (actual suitability) to 5.8 t/ha (potential suitability). This increase highlights the importance of using modest inputs to boost soil productivity for maize.

Key words: Lateritic toposequence, rain-fed maize, land suitability classification, actual yield, potential yields, Cameroon Western Highlands.

INTRODUCTION

The cultivation of maize is of great importance for food security and economic development, particularly in sub-

Saharan Africa, where maize is grown on more than 25 million ha and production attains 38 million tons (Setimela et al., 2017). Maize plays a vital role as a staple food, comparable to rice or wheat in Asia (Woomer et al., 2024). However, yields remain low, ranging from 1.5 to 2 t/ha under smallholder conditions (Setimela et al., 2017). In Cameroon, two-thirds of the population consume maize, and the demand keeps increasing (Ntsama Etoundi and Kamgnia Dia, 2008; Nzossié et al., 2010). Determinants of the adoption of improved varieties of Maize in Cameroon (case of cms 8704). This trend is particularly remarkable in urban areas, especially during periods of food shortage when maize becomes crucial for food security (Nzossié et al., 2008). Although the potential yield of improved varieties reaches 4.5 to 6 t/ha, the average yield remains at 1.84 t/ha (Fani et al., 2023; Meyo and Egoh, 2020). In the Cameroon Western Highlands, the variability of soil and climate poses significant challenges for optimized maize production (Nanganoa et al., 2020; Fotso et al., 2024). Climate change events affect water availability and soil nutrient availability (Ngala et al., 2020). This often prompts farmers to sow prematurely at the risk of crop failure (Sultan et al., 2020; Deffo et al., 2024). According to some farmers, sowing as soon as the first rains, without waiting for the season to start, exposes them to sowing failure (Wuchu et al., 2024). Likewise, sowing when the rain falls without any plant cover results in soil surface erosion (Derrouch et al., 2020; Salack et al., 2020). Soil-climate performance for food crops in the region ranges from excellent to poor (Enang et al., 2016), and their accurate behavior can be difficult to predict. Despite the importance of maize in developing countries, there is a gap in knowledge about the cultivation capabilities of the different land units on lateritic toposequences. Particularly in the Cameroon Western Highlands, soil and climatic variations can lead to significant differences in maize productivity, making it difficult to adopt uniform farming practices. This work aims to characterize the land units and evaluate their suitability for maize cultivation along a lateritic toposequence in Dschang (Cameroon Western Highlands). This will help to identify the best farming practices adapted to local conditions and contribute to the sustainable management of agricultural resources.

MATERIALS AND METHODS

Study area

Dschang Sub-division is located between longitudes 10°03′20″ and 10°05′20″ East, and latitudes 5°25′30″ and 5°27′00″ North (Figure 1). The mean altitude is 1400 masl. The area is under a humid tropical climate, with two seasons which are a rainy season from mid-March to mid-November (8 months) and a dry season from mid-November to mid-March (4 months). The average annual temperature is 21°C and annual rainfall is 1900 mm, a crucial factor for local agriculture (Mayi et al., 2019). The vegetation consists of herbaceous savannahs and fringes of a highly anthropogenised forest. The drainage network belongs to the Menoua catchment area, the main tributary of the Nkam. Lateritic soils dominate the mid-slopes and mountain tops, while Gleysols are found in the valleys. Azonal edaphic soils are also found in the marshy valleys (Mbibueh et al., 2024). The soil of Dschang originates from at least five rock types and reflects the geological diversity of Western Cameroon (Tsopkeng et al., 2023; Momo et al., 2023). The area is located along the Cameroon Volcanic Line, precisely on the southern slope of Mount Bambouto in the Cameroon Western Highlands. It is comprised of various magmatic rocks (basalt, trachyte, phonolites, and granite) that overlie the Precambrian basement rocks. These basement rocks are Neo-Proterozoic granite-gneiss intruded by late Proterozoic granitoids (Nono et al., 2009). The main activity of the inhabitants is agriculture, but commercial activities are also carried out.

Soil survey and morphological characterization

The soil survey was carried out following an N-S-orienting toposequence, using the method recommended by Boulet et al. (1982). This method involves studying the soils that follow one another from the summit to the footslope of a landscape, along the line of the steepest slope of the toposequence, where soil profiles have been opened, each identified by its topographic position (Schoeneberger et al., 2012). The toposequence studied comprises five profiles which are one at the summit (plateau), one at the upper slope, one at the mid-slope, one at the lower slope, and one in the lowland. Based on the shape of the relief, three profiles (P1, P2, and P3) were initially aligned. However, to better define the spatial and lateral boundaries of the soil units, other intermediate profiles (P4 and P5) were dug in between P1, P2, and P3, to permit a better understanding of the soil morphological organization and lateral distribution. This choice of profile locations along the toposequence takes into account the morphopedological context of the study site, intending to laterally link horizons along successive verticals while reducing uncertainty as far as possible (Boulet et al., 1982). Soils were classified using WRB for soil resources (IUSS Working Group WRB, 2022).

Soil sample collection

The soil profiles were described following standard procedures and soil samples were collected per horizon according to FAO (2006). To determine the bulk density, undisturbed samples were collected using 100 cm^3 cylindrical rings. The soil samples were carefully stored in clean plastic bags and taken to the laboratory for further description, processing, and analysis. The disturbed samples from each horizon were crushed and sieved using a 2 mm mesh sieve to obtain the fine earth fraction (≤ 2 mm diameter) and coarse fragments (> 2 mm diameter).

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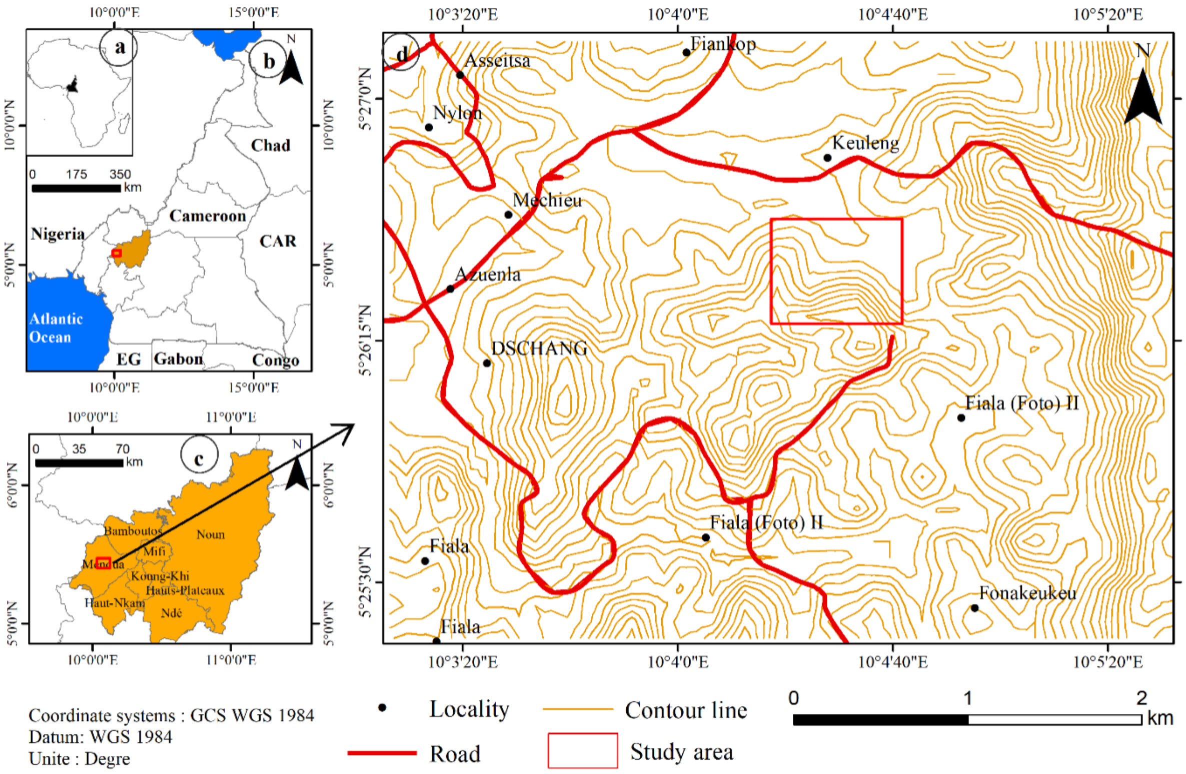

Figure 1. Location map of the study area; a. location of Cameroon in Africa; b. location of the Western Region in Cameroon; c. location of the study area in the West Region; d. map of the study area.

Table 1. Precipitation and potential evapotranspiration data

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
Precipitation	11.75	34.66	105.5	204.3	229.6	312.2	347.6	360.5	340.8	305.5	88.3	14.2	2354.91
ETP (mm)	111.65	119.4	116.8	109.4	104.0	90.7	71.9	68.2	85.1	92.5	99.8	104.5	1173.95
ETP/2 (mm)	55.8	59.7	58.4	54.7	52.0	45.3	35.9	34.1	42.6	46.2	49.9	52.2	586.80

Laboratory soil analysis

The physicochemical analyses were carried out at the Research Unit of Soil Analysis and Environmental Chemistry of the University of Dschang (Cameroon). Soil moisture was obtained after weighing and oven-drying a soil sample at 105°C for 24 h. Particle density (Dp) was determined by the pycnometer method (Heiskanen, 1992). Based on procedures described by Pauwels et al. (1992), unless otherwise specified, bulk density (Da) was measured by calculating the ratio between the dry mass at 105°C and the total volume of the soil. Porosity was estimated from bulk density (Da) and particle density (Dp). Particle size distribution was determined using the Robinson pipette method. Soil texture was classified according to the USDA textural triangle (USDA, 2017). Soil pH was determined in a soil/water ratio of 1:2.5 (pH-H_2O) and a soil/1N KCl mixture of 1:2.5 (pH-KCl). The Organic carbon (OC) was dosed using the Walkley and Black method while total nitrogen (TN) was determined by the Kjeldahl method. Exchangeable bases were measured by the Metson method. The cation exchange capacity (CEC) was measured using the exchangeable bases after rinsing with alcohol and the introduction of a 1N KCl solution. The pH 7 CEC was obtained with a 1 N NH_4OAc solution at pH 7, while the CEC in clay was assessed using the Cu-triethylene-tetramine (Cu-Trien) method (Grove et al., 1982).

Determination of growing season and wet season in the study area

Analysis of the rainfall data in combination with the reference evapotranspiration (ETP) and its half (1/2 ETP) led to the determination of the growing season and the wet season for this study area over the entire 30-year period (1990-2021). Thus, the growing season in Dschang begins on 26th February and ends on 30th November, while the wet season begins on 21st March and ends on 8th November (Table 1 and Figure 2). Potential evapotranspiration (PET) was estimated using the radiation method (Jensen et al., 1990): climatic attributes were delineated using distinct scoring systems. These attributes were ascertained through

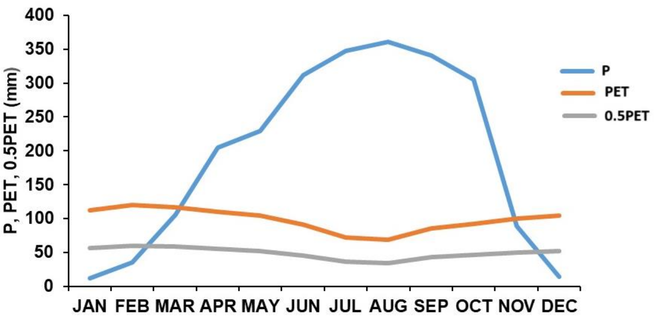

Figure 2. Growing period type for the locality of Dschang.

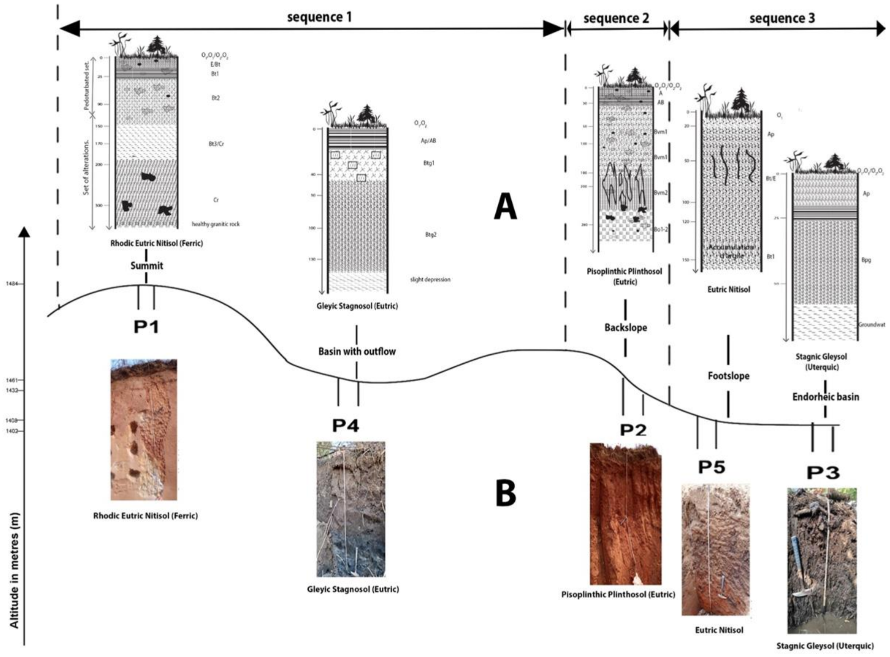

Figure 3. Morphological organization of soils along the lateritic toposequence. (A) Photographs of profiles, ((B) diagrams of the profile.

the application of the Storie method (a parametric approach) as articulated by Sys et al. (1993):

$$I = Ax \frac{B}{100} \ x \ \frac{C}{100} x \frac{D}{100} \ x \ \frac{E}{100} \ x \qquad (1)$$

where I is the index, while A, B, C, D, E, and so forth denote the various scores assigned to each property.

The climatic attributes considered include precipitation, temperature, and relative humidity, whereas the soil attributes comprise topography (slope), moisture (flooding and drainage), soil physical characteristics (texture, volumetric percentage of coarse fragments, and soil depth), fertility characteristics (CEC, base saturation, organic carbon, and pH), as well as electrical conductivity and exchangeable sodium percentage.

The biophysical characteristics of the different studied sites are shown in Table 2. Through the assessment of the land index and the application of the criteria established by Sys et al. (1991) (Table 3) in reference to Beernaert and Bitondo (1993), the qualitative land suitability categories (Table 4) and the factors impeding plant growth across the various soil series for each crop were identified. Table 5 shows the critical thresholds for nutrients and soil fertility parameters.

RESULTS AND DISCUSSION

Soil characteristics

The depth of the surface horizon varies between 25 and 40 cm, over the entire topographical sequences (Figure 3). Although this depth fluctuates in certain sequences, it does not vary considerably from the top to the bottom of the slope. In the upper slope (P4), the depth increased by 10 to 15 cm, which is thought to be the result of an accumulation of loose material, especially as it is located just at the ‘mouth’ of the erosive incision caused by the abrupt break in the relatively steep slope of 27 to 36%,

Table 2. Biophysical characteristics of the study site

Site characteristics		Summit	Basin with outflow	Backslope	Footslope	Endorheic basin
Geographic	Long. (East)	010°04'25.0"	010°04'29.1"	010°04'27.4"	010°04'36.9"	010°04'37.5"
Coordinates	Lat. (North)	05°26'21.7"	05°26'24.6"	05°26'23.6"	05°26'32.5"	05°26'32.8"
Altitude (m)		1484	1461	1432	1408	1402
Slope (degree)		14-19	27-36	20-25	8 - 13	> 7
Vegetation		Grassed Savannah	Grassed Savannah	Grassed Savannah	tree-shrub	Forest gallery
Parent rock		Granite and Gneiss	Granite	Granite	Granite colluvial diposits	Granite diposits
Soil type		Rhodic Eutric Nitisol (Ferric)	Gleyic Stagnosol (Eutric)	Pisoplinthic Plinthosol (Eutric)	Eutric Nitisol	Typic Hapludalfs
Soil use		Subsistence farming	Subsistence farming	Subsistence farming	Subsistence farming	Market gardening
Erosion		Moderate	Moderate	Moderate	None	None
Human activity		Infrastructure	Infrastructure	Infrastructure	Infrastructure	-

Table 3. Qualitative land suitability classes for the different land indices.

Land index	Definition	Symbol
90-100	Highly suitable with no limitations	S1- 0
85-90	Highly suitable with slight limitations	S1- 0/1
75-85	Highly suitable with slight limitations	S1-1
60-75	Highly suitable to moderately suitable	S1-1/S2
50-60	Moderately suitable	S2
40-50	Moderately suitable to marginally suitable	S2/S3
25-40	Marginally suitable	S3
15-25	Marginally suitable to not suitable	S3/N
0-15	Not suitable	N

Source: Beernaert and Bitondo (1993).

which divides the material upstream and downstream. This is in line with studies by Yoboué (1999). Thus, the spatial distribution of soil horizons on the slopes reveals both a deep pedological differentiation discordant with the prevailing topography and a more superficial differentiation consistent with the relief (Boulet et al., 1982).

Soil color at the summit and Backslope areas are characterized by predominantly weak red tones (2.5YR 4/2), influenced by disturbances such as cultivation and erosion, indicating that soil management affects color (Viguier, 1993). The backslope has a uniform red color due to the presence of iron oxide. In contrast, the depressions and endorheic basins show a range of colors (5YR, 2.5Y, 10YR, 5Y), influenced by the temporary or permanent presence of water and soil management practices. These color variations are also linked to drainage and hydromorphic conditions, as can be seen in the sub-surface

Table 4. Suitability classification of soil units.

Suitable order [S]	Land on which the category of continuing use envisaged provides benefits justifying the necessary inputs, without the risk of causing unacceptable harm to the land resources.
Unfit order [N]	Land whose qualities seem to preclude the category of continuous use envisaged.
S1-0	Very high suitability, no limitations
S1-1	High suitability, slight limitations.
S2	Average suitability, moderate limitations
S3	Marginal suitability, severe limitations
N1	Currently unsuitable, very severe but correctable limitations

Source: Sys et al. (1993) and FAO (1996).

Table 5. Classification of critical fertility levels in soils for organic carbon (OC), total nitrogen (TN), available phosphorous (P), cation exchange capacity (CEC), base saturation (BS), exchangeable cations, and soil reaction

Soil properties (< 2 mm fraction)	Critical fertility level				
	Very low	Low	Medium	High	Very high
OC (%)	< 0.4	0.4-1.0	1.0-1.8	1.8-3.0	> 3.0
Total N (%)	< 0.05	0.05 - 0.125	0.125 - 0.225	0.225 - 0.30	> 0.30
C/N	-	< 10 = good	10 - 14 = medium	> 14 = poor	-
Ca^{2+} (cmol(+) kg^{-1})	< 2	2 – 5	5 - 10	10 - 20	> 20
Mg^{2+} (cmol(+) kg^{-1})	< 0.5	0.5 - 1.5	1.5 - 3.0	3 - 8	> 8
K^{+}(cmol(+) kg^{-1})	< 0.1	0.1 - 0.3	0.3 - 0.6	0.6 -1.2	> 1.2
Na^{+} (cmol(+) kg^{-1})	< 0.1	0.1 - 0.3	0.3 - 0.7	0.7 - 2.0	> 2.0
P (mgkg^{-1})	< 7	7 – 16	16 - 46	> 46	-
pH (H$_2$O)	≤5.5 (strongly acidic)	5.6 - 6.0 (moderately acidic)	6.1 - 6.5 (slightly acidic)	7.4 - 7.8 (slightly alkaline)	7.9 - 8.4 (moderately alkaline)
CEC (cmol(+) kg^{-1})	< 6	6 – 12	12 - 25	25 - 40	> 40
BS (%)	0 - 20	21 – 40	41 - 60	61 - 80	81 - 100
EC (dS/m)	< 2 (non - saline)	2 – 4 (slightly saline)	4 – 8 (moderately saline)	8 – 16 (highly saline)	> 16 (extremely saline)

horizons of fluvial soils, where darker hues indicate a reduction in iron following prolonged flooding (Raunet, 1985). The summit and backslope positions harbor light red-colored soils, principally due to more advanced weathering accompanied by accumulation of sesquioxides. Depressions and endorheic basins on the other hand present a wide range of colors which are probably influenced by soil management practices and water fluctuations causing gleysation or mottling, common in temporarily flooded environments (Viguier, 1993; Raunet, 1985).

The particle size distribution analysis reveals that except for the basin with outflow, the studied soils in the other sequences are generally silty. In

Table 6. Morphological characteristics of the soils per topographic position.

Topography and slope shape	Litter		Horizon designation	Depth (cm)	Colour (dry)	Structure**	#Consistency			#Boundary	Percentages of coarse fragments
	Types of layers	Thickness (cm)					Dry	Moist	Wet		
(P1)	O$_1$, O$_1$/O$_2$, O$_2$	25	A	0-25	2.5YR 4/2	Grn	sh	vfr	s/p	-	3-5
			E/Bt	25-90	2.5YR 5/4	fph	sh	vfr	s/p	gs	10
			Bt$_1$	90-150	10R 4/6	cph	vfr	Fr	s/p	gs	None
			Bt$_2$	150-170	10R 4/6	ms	vfr	Fr	s/p	cs	None
			Bt$_3$/Cr	170-220/280	5YR 5/8	mw	h	Fr	s/p	cs	20
			Cr	220/280-300+	2.5Y 6/8 to 10YR 8/3	mr	h	Fr	s/p	ds	20
(P4)	O$_1$, O$_2$	25	Ap/AB	0-50	5YR 3/3	cph	sh	vfr	s/p	-	None
			Btg1	50-100	2.5YR 4/6	ms	sh	vfr	s/p	gs	None
			Btg2	100-130	7.5YR N3/0	-	sh	vfr	s/p	ds	3
(P2)	O$_1$, O$_1$/O$_2$, O$_2$	5	A	0-30	2.5YR 4/2 to 10R 4/6	pr	sh	vfr	s/p	-	38
			AB	30-50	10R 4/6	fph	sh	Fr	s/p	cs	40
			Bvm$_1$	50-100	10R 4/6	cph	h	Fr	s/p	gs	44
			Bvm$_2$	100-180	5YR 5/8	ms	h	Fr	s/p	gs	46
			Bo$_1$	180-200	10YR 7/1	mw	h	Fr	s/p	gs	49
			Bo$_2$	200-280	7.5YR 5/8	mw	h	Fr	s/p	gs	57
(P5)	O$_1$	10	Ap	0-30	5YR 4/4	Grn	sh	Vfr	s/p	-	None
			Bt/E	30-70	2.5YR 5/4	fph	l	Vfr	s/p	gs	None
			Bt$_1$	70-150	2.5YR 4/6	ms	l	Fr	s/po	as	None
(P3)	O$_1$, O$_1$/O$_2$, O$_2$	15	Ap	0-25	5YR 3/4	Grn	sh	Fr	s/p	-	None
			Bpg	25-50+	2.5Y 3/4	m	l	Vfr	s/po	ds	None

*l= loam; cl= silty clay loam, scl= sandy clay loam, sl= Sandy loam; ** gr= granular, Grn= grinder, ph= Polyhedral, fph= fine polyhedral, cph= Coarse polyhedral, m= massive, ms= massive soil aggregate structure, mw= massive strongly chemically weathered (e.g. saprolite), mr= massive not or only slightly chemically weathered, pr= prismatic; # h= hard, l= loose, sh= slightly hard, fr= friable, vfr= very friable, po= non-plastic; ## cs= clear smooth, ds= diffuse smooth, as= abrupt smooth, and gs= gradual smooth.

a basin with outflow, the soils are silty clay to clayey silt. This mixture of fine particles (silt and clay) and coarse particles (sand) promotes soil permeability and porosity, ensuring the availability of water and nutrients needed by plants. The high silt content makes the soil susceptible to capping, under the effect of rainfall, it clumps together and an impermeable layer forms on the surface, hindering water infiltration and seed emergence. However, this proportion falls in soils that are not highly valued, to the benefit of coarse elements (P4). The high sand content is recorded at the footslope, where there are quartz grains. This increase in the proportion of sand towards the bottom of the slopes (P4 and P3) is probably due to the removal and downslope transportation of finer elements, leaving coarse elements at the summit and slopes (Ruhe and Walker, 1968). The high sand content in profile 4 explains the coarse texture of the poorly developed soils that characterize the basin with outflow as a whole. The soil structure is lumpy to polyhedral at the surface, except on the backslope where it is prismatic. In all other topographic positions, sub-surface and deep horizons are generally massive (Table 6). The soil physico-chemeical properties are shown in Table 7A.

The soil pH.H_2O fluctuates with no clear upward or downward trend. It drops from 5.9 at the peak to 5.8 on the basin with outflow and backslope. On the basin with outflow, it tends to increase (pH 6.2) and then decreases towards the endorheic basin, with values varying from 5.3 at the surface to 5.5 at depth. In the other topographical positions, apart from the very acidic sub-surface horizon (AB) on the backslope (pH 4.9), this critical threshold is generally exceeded on the surface horizons. However, on backslope, a high pH value (6.9) was recorded in the deep horizon. The increase in pH at depth could be explained by the leaching of fine elements from the surface to depth, linked to the accumulation of nutrients such as cations and anions in the deep horizons. Thus, there appears to be no direct relationship between pH and topographical position as opposed to other studies (Ollier, 1973) where pH varied with topographical position; this is probably, due to the differential pedogenetic processes currently prevailing in the study site (Frisch and Gerrard, 1981).

The CEC evolves as a function of the topographical position, increasing as one moves from the top to the bottom of the hill, varying between 20.3 and 24.5. This is justified by the significant contribution of the latter to its expression, in line with Frisch and Gerrard (1981), who pointed this out in his study of the relationship between landforms and soil types in the Bambouto mountain of Western Cameroon. Strong correlations between SOM and CEC have been demonstrated (Sanchez and Lacombe, 1976). The CEC values are in the range of kaolinitic soils marked by low nutrient reserves (Beernaert and Bitondo, 1991).

The sum of exchangeable bases (SEB) follows the same trend as the CEC. The topographical variability indicates an upstream zone where the levels of the SEB are higher, between 12.46 and 13.81 cmol(+)kg^{-1}, a median zone where they are moderately high, 12.49, and a downstream zone where they are lower, 9.36 (cmol(+)kg^{-1}).

The evolution of certain exchangeable bases does not follow that of CEC in certain surface horizons (Table 7A). The expected relationship between CEC and the exchangeable base is not evident here for certain elements possibly due to leaching under humid tropical conditions with abundant rainfall favored by the steep slopes. These findings agree with the works of Frisch and Gerrard (1981).

The SOM content, C/N ratio, and TN vary from the surface (H1) to the sub-surface horizons, according to the different sequences (Table 7A). Higher SOM content was observed at the surface (less than 40 cm depth) compared to depth, and this was true for all topographical segments. The lower levels of organic matter recorded in P1 and P2 are certainly linked to cultivation, which reduces the stock of SOM, and to water erosion (Pieri, 1989). The topographic position of the basin with outflow (P4) has a higher SOM content, with a content of 6.4%. The Footslope concave linear (P5) and endorheic basin linear (P3), with contents of 4.1 and 4.8% respectively, are estimated to be rich in SOM. The relative richness in SOM of the surface horizons of the endorheic basin and basin with outflow, as observed in the present study and that of Akassimadou and Yao-Kouamé (2014), could also be explained by the hydromorphic, which prevents SOM mineralization, causing its accumulation at the surface horizons (Lavigne et al., 1996). This process can considerably reduce soil pH, leading to the formation of very acid soils with low CEC (Akassimadou and Yao-Kouamé, 2014).

Table 7B shows an overview of the nutrient dynamics and fetidity indices of the soil sequence, to reveal crucial information about the agronomic potential of the soils.

The silt/clay ratios of all the soil layers are greater than 0.75 indicating old-age pedogenetic processes according to Sombroek and Zonneveld (1971). This rejuvenation of the toposequence is probably related to erosion promoted by the steep slopes (Pereira et al., 2022).

The C/N ratios in the surface horizons vary from 4.78 to 22.16, the highest being obtained in the upper slope soil (P4) while the lowest is obtained in the topsoil (P1). The C/N ratio is equal to 22.16 in the soil of the basin with outflow, which reflects the poor decomposition of organic matter in this soil; it is a poorly draining soil, whose TN requirements are not assured according to Prusty et al. (1999). The C/N ratio reflects the state of mineralization of the organic matter (Boyer, 1989). According to Duchaufour (1997), this C/N value is generally good at the surface (generally < 10), except for the poorly drained footslope soils (P4) (>20). According to Feng et al. (2021), slope position and land use have a strong impact on the C/N ratio.

The Ca/Mg ratio values vary from 1.19 to 3.03. The high Ca/Mg ratio recorded at the bottom of the slope (P3) may indicate soil rich in calcium, which is often favorable for plants, whereas a low ratio of 1.19 obtained at the top of the slope (P1) could indicate a mineral imbalance.

The evolution of Mg/K does not follow that of Ca/Mg, with the lowest value of 0.31 recorded at the bottom and the highest at the top (1.35). The 0.31 ratio suggests a dominance of potassium, while P1 H1 (1.35) shows a better balance. The trend in the S/T ratio is up and down, with no clear upward or downward trend. It goes from 61.38 at the summit to 53 at the footslope and 51.01 at the mid-slope, then 66.70 at the bottom of the slope, and finally 41.78 at the bottom. The change in mg/K, with a minimum of 0.31 at P3 and a maximum of 1.35 at P1, is more illustrative of nutrient dynamics, where K relative dominance at low elevations can hinder magnesium uptake, while a balanced ratio at peak favors better nutrient uptake (Kasinath et al., 2014).

The (Ca+Mg)/K is low (<15) in all the sequences. According to Beernaert and Bitondo (1991), this implies a

Table 7. Physical and chemical properties of soils at various topographical positions (A) and nutrient/fertility indices (B).

Position (A)	Horizon (depth in cm)	Particle size distribution			Textural class	BD	EC	RH	pH	CEC -pH 7	CEC clay	OM	N (%)		Avail. P	Exch. Cations (cmol(+) kg^{-1})				BS
		Sand (%)	Silt (%)	Clay (%)	(FAO, 1996)	(g/cm^3)	(dS/m)	(%)	(H$_2$O)	(Cmol$_+$/kg)	(cmol(+) kg^{-1})	(%)	Total N	C/N	mgkg^{-1})	Ca^{2+}	Mg^{2+}	K$^+$	Na$^+$	(%)
Summit	H1 (0-25)	28	40	32	CL	0.82	0.31	13.59	5.9	20.3	18. 1	2.0	0.24	4.78	20.94	5.0	4.2	3.1	0.02	61.3
	H2 (25-90)	36	40	24	L	0.68	0.25	28.90	5.2	16.7	7.7	7.8	0.14	30.96	8.63	1.1	2.5	4.3	0.06	48.5
	H3 (90-170)	28	42	30	CL	0.90	0.22	15.88	5.5	14.7	11.1	3.2	0.03	53.20	9.23	1.6	1.4	7.3	0.10	71.1
	170–300	42	28	30	SCL	0.95	0.26	15.28	5.2	13.3	11.1	2.0	0.09	11.79	12.97	1.9	1.0	0.3	0.06	25.4
Basin with outflow	H1 (0–40)	42	28	30	SCL	0.90	0.35	4.65	5.8	25.9	18.5	6.4	0.16	22.16	7.18	6.2	4.9	2.5	0.06	53.3
	H2 (40–130)	36	26	38	CL	0.75	0.27	36.09	6.8	16.1	7. 7	7.2	0.26	16.02	24.20	3.6	1.2	3.3	0.52	53.6
Backslope	H1 (0–30)	30	40	30	CL	0.98	0.35	4.89	5.8	24.5	21.1	2.9	0.23	7.24	8.39	5.4	3.3	4.3	0.06	51.0
	H2 (30–160)	28	34	38	CL	0.87	0.16	25.68	4.9	14.9	13.1	1.3	0.10	7.22	11.04	4.4	2.7	3.1	0.35	56.2
	H3 (160–280 cm)	32	36	32	SCL	1.16	0.31	19.85	6.9	17.25	16.85	0.3	0.15	1.34	10.44	2.2	1.7	8.0	0.05	81.9
Footslope	H1 (0– 30)	28	44	26	L	0.80	0.24	20.89	6.2	20.9	16.1	4.1	0.30	8.01	23.24	5.4	2.3	6.1	0.03	66.7
	H2 (30 – 70)	30	44	26	L	0.57	0.25	32.88	6.1	21.7	16.9	4.1	0.09	24.63	11.04	4.4	2.6	2.1	0.06	42.8
	H3 (70 – 150)	32	42	26	SCL	0.73	0.32	25.71	6.2	15.6	15	0.5	0.07	4.47	18.65	2.2	4.3	2.0	0.09	55.6
Endorheic basin	H1 (0–25)	36	34	30	SCL	0.23	0.29	65.08	5.3	22.4	16.8	4.8	0.16	6.37	6.33	3.8	1.2	4.1	0.02	41.7
	H2 (25–50+)	24	48	28	sl	0.41	0.33	51.35	5.5	17.3	11.1	5.3	0.26	10.07	17.80	4	1.2	3.4	0.05	50.9

Profile (B)	P1				P2			P3		P4		P5		
Horizons	**H1**	**H2**	**H3**	**H4**	**H1**	**H2**	**H3**	**H1**	**H2**	**H1**	**H2**	**H1**	**H2**	**H3**
Silt /clay ratio	1.25	1.67	1.4	0.93	1.33	0.89	1.13	1.13	1.71	9.33	6.84	1.69	1.69	1.50
C/N ratio	4.78	30.96	53.20	11.79	7.24	7.22	1.34	6.37	10.07	22.16	16.02	8.01	24.63	4.47
S/T ratio	61.38	48.51	71.10	25.43	51.01	56.26	81.99	41.78	50.91	53.33	53.63	66.70	42.81	55.61
Ca/Mg ratio	1.19	0.44	1.14	1.92	1.61	1.65	1.27	3.03	3.13	1.26	3.00	2.33	1.72	0.52
Mg/K ratio	1.35	0.59	0.19	3.00	0.77	0.86	0.22	0.31	0.37	1.94	0.36	0.37	1.22	2.15
(Ca+Mg)/K	2.93	0.85	0.41	8.76	2	2.29	0.49	1.24	1.52	4.39	1.45	1.25	3.30	3.28
CEC/clay ratio	0.63	0.70	0.49	0.44	0.86	0.42	0.82	0.39	0.54	0.80	0.83	0.60	0.75	0.62
Ca/Mg/K	41/34/25	13/12/54	15/14/71	59/31/10	41/36/33	43/26/31	19/15/66	42/14/44	46/15/39	45/36/19	44/15/41	39/17/44	49/28/23	27/50/23
CRC	0.53/1.8/4.1*	0.17/0.66/9*	0.19/0.77/2.8*	0.77/1.72*/1.66	0.53/2/5.5*	0.53/1.44/7.4*	0.2/0.8/11*	0.5/0.7/7.3*	0.6/0.8/5.6*	0.5/2/3.1	0.5/0.8/6.8*	0.5/0.9/7.3*	0.6/1.5/3.8*	0.3/2.7/3.8*
ESP (%)	0.09	0.35	0.68	0.45	0.24	2.34	0.28	0.08	0.28	0.23	3.22	0.14	0.57	0.63

A (BD = Bulk density, EC = Electrical conductivity, RH= Moisture retention, BS= base saturation, Avl. P= available phosphorus, Exch.= exchangeable, C= clay, CL= Clayey loam, SCL= sandy clayey loam). B (CRC: Coefficient of relative concentration, *: most concentrated cation that determines the direction of the equilibrium, ESP: exchangeable sodium percentage, L/S: silt-to-sand ratio; L/A: silt-to-clay ratio).

potential Ca and Mg deficiency in the soil sequence.

The exchangeable Na% (ESP) values are decreasing on all topographic segments and are generally low, with peaks in certain horizons such as 0.24 (H1 P2) at mid-slope to 0.08 (H1 P3) at the bottom of the slope. Such low ESP levels are typically low soil salinity favorable for plant growth.

The Ca/Mg/K ratio shows that values vary greatly along the slope and reveal a general cation imbalance compared to the ideal situation (Ca/Mg/K=76/18/6) for optimum root absorption according to Beernaert and Bitondo (1991). There is a general potential deficiency in Ca.

The coefficient of relative concentration (CRC) indicates that K is the most concentrated cation that determines the direction of cationic equilibrium (Martin, 1979). The variation in the Ca/Mg/K ratio at different slope positions indicates important implications for soil nutrient availability and crop behavior. The high relative concentration of exchangeable K could be attributed to the presence of a small amount of illite in the profiles.

Assessment of land suitability for rain-fed maize

The climatic indices for maize are shown in Table 8. The summit, basin with outflow, backslope, footslope, and endorheic basin topographic positions show the same climatic suitability for the aforementioned crop during the growing cycle (February, March, April, and May). The climate is moderately suitable (S3), due to limitations imposed by precipitation in the fourth month, mean minimum temperature during the growing cycle, relative humidity in the fourth month, and the development stage in the second month.

Soil and climate assessment for rain-fed cultivation of maize

Tables 8, 9, 10, and 11 show the results of the biophysical assessment of the five land units for the actual land potential suitability of the study area. The actual suitability classes correspond to the suitability of the land for cultivation before any development in the direction of land improvement, while the potential suitability classes refer to the existence of development in the direction of land improvement. These results show that units 1 (Rhodic Eutric Nitisol (Ferric)) and 4 (Eutric Nitisol) are currently marginal (S3) for maize cultivation because of climatic and soil physical constraints. On the other hand, units 2, 3, and 5 ((Gleyic Stagnosol (Eutric), Pisoplinthic Plinthosol (Eutric) and Stagnic Gleysol (Uterquic), respectively) are currently unsuitable (N2 and N) for maize cultivation, mainly due to poor aeration in the root zone and problems linked to topography. There are also some constraints related to the chemical fertility of the soil. In land use planning, assessing land suitability is crucial to optimizing agricultural productivity, particularly for crops such as maize. The S1 and S2 classes are frequently considered sustainable, while the S3 and N classes are not sustainable, and may still face significant constraints that hinder optimal agricultural practices (Alemayehu, 2023; Hussain et al., 2024). Addressing these challenges requires a holistic approach to land management and planning. However, the suitability of land for all types of uses in the project area must always be assessed. Thus, in the case of this study area, with minor and/or major land improvements, the current constraints can be lifted and, as a result, there will be a significant improvement in the level of land suitability for maize cultivation. These improvements mainly concern adequate soil fertilization, especially for the endorheic basin landscape (mainly pH) where Stagnic Gleysol (Uterquic) dominates. This development is also intended to improve internal soil drainage conditions in order to establish a suitable air-water balance in the rooting zone of the colluvial-alluvial soils of Eutric Nitisol and Gleyic Stagnosol (Eutric). In the case of Pisoplinthic Plinthosol (Eutric), the high coarse element content is a severe limitation for the rooting zone. In all cases, topography and slopes condition the cropping systems practiced, and certain slope thresholds constitute limitations to the optimal development of agriculture in the study area. This can be corrected by cultivation in the shape of contour lines. The high level of coarse elements can be compensated for by a particularly high organic matter content (often over 4% under natural vegetation). In these soils, manual dethatching can be envisaged to encourage mechanization. Such corrections have led to the determination of three classes of land potential suitability (Table 9) which are Rhodic Eutric Nitisol (Ferric) may become moderately suitable for maize, Gleyic Stagnosol (Eutric), Pisoplinthic Plinthosol (Eutric) and Stagnic Gleysol (Uterquic) become marginally suitable while Luvisols fragic clayic become suitable. Table 9 shows the extent of each of these three potential suitability classes in the study area. Thus, the study area shows 47.3% of potentially S3 (marginally suitable) soils, 34.60% of S1 (suitable) soils, and 18.07% of S2 (moderately suitable) soils (Table 9).

Actual and potential yield estimates for the five land units

The different land units in their actual suitability classes are capable of producing (Tables 10 and 12). Comparing the actual land potential maize yields estimated for the five land units under both medium and low input farming with the land suitability classes for this crop shows a very Nitisol (Ferric), Gleyic Stagnosol (Eutric), Pisoplinthic Plinthosol (Eutric)) and lowlands (Eutric Nitisol and Stagnic Gleysol (Uterquic)). Yields in traditional agriculture could be associated with the actual suitability of the land, given the low level of input, while those in

Table 8. Assessment of the climatic characteristics of the study area for rain-fed maize cultivation, 120-day cycle.

Climatic characteristic	Values or ratings	Parametric values	Degree of limitation	Suitability classes
Precipitation A (mm)				
Rainfall of growing cycle	811.18	96.48	0	S1-0
Precipitation of the 1st month	98.00	83	2	S2
Precipitation of the 2nd month	195.81	98.27	0	S1-0
Precipitation of the 3rd month	218.05	96.41	0	S1-0
Precipitation of the 4th month	299.32	81.89*	2	S2
Temperature B (°C)				
The average temperature of the growing cycle	24.64	98.3	0	S1-0
Average minimum temperature of the growing cycle	17.12	97.8*	0	S1-0
Relative humidity C (%)				
Relative humidity of 2nd month	85.51	95	1	S1-1
Relative humidity of 4th month	89. 03	61.62*	2	S2
n/N Ratio				
n/N of 2nd-month development stage	0.54	97	0	S1-0
n/N of 4th-month development stage	0.48	60*	2	S2
Climatic Index (CI)	-	29.61	-	-
Climatic Rating (CR)	-	43.32	-	-

S1-0: No limitation, very suitable, optimal yield (95 - 100%); S1-1: slight limitation, suitable, almost optimal yield (85 - 95%); S2: moderate limitation, moderately suitable, acceptable yield (60 - 85%); *the most limiting characteristic of each group; n: actual insolation (hours/day); N: maximum insolation (day length) (hours/day).

Table 9. Summary of the potential suitability of the five land units for rain-fed maize cultivation

Soil units	Actual suitability	Potential suitability	Estimated yields (t/ha)	Area (ha)	Area (%)
Soil units N°, 2, 3 and 5	N/N2	S3	0 - 1.95	28	47
Soil unit N°1	S3	S2	0. 97 - 2.27	11	18
Soil unit N°4	S3	S1	5.2	21	35

modern agriculture correspond more closely to the potential suitability of the land, given the average consistent trend, between uplands (Rhodic Eutric level of input for maize cultivation in this context. It is observed that that yields with low input levels rise from 0.9 t/ha (actual suitability) to 4 t/ha (potential suitability). Medium-input yields range from 2.27 t/ha (actual suitability) to 5.8 t/ha (potential suitability).

Table 10. Estimated actual maize yields (in t/ha).

Land units	Suitability class	Actual yield (t/ha)	
		Low level of inputs	The average level of input
Rhodic Eutric Nitisol (Ferric)	S3, t	1.35	1.95
Gleyic Stagnosol (Eutric)	N2, tw	1.35	1.95
Pisoplinthic Plinthosol (Eutric)	N1, t, s	1.35	1.95
Eutric Nitisol	S3, ct	0.67-1.57	0.97-2.27
Stagnic Gleysol (Uterquic)	N2, w	0.9	1.3

S3: Severe limitation, marginally suitable, low yield (85% - 95%); N1: very severe limitation, not recommended, but potentially suitable, unacceptable, very low yield (25% - 40%); N2: very severe limitation, not recommended, potentially not suitable, unacceptable yield (0% - 25%).

Table 11. Estimated potential yields (in t/ha) for maize crops.

Land units	Potential Suitability class	Potential yields (t/ha)	
		Low level of inputs	The average level of input
Rhodic Eutric Nitisol (Ferric)	S2	1.8-3.6	2.6-5.2
Gleyic Stagnosol (Eutric)	S3	0.9-2.4	1.3-3.5
Pisoplinthic Plinthosol (Eutric)	S3	0.9-2.4	1.3-3.5
Eutric Nitisol	S1	2.7-4	3.9-5.8
Stagnic Gleysol (Uterquic)	S3	0.6-1.5	0.9-2.2

The FAO system assesses land based on climatic conditions, soil properties, and crop requirements, ensuring a holistic assessment (Taati and Sarmadian, 2015). The classification of land into suitability classes (S1 to N) allows for targeted farming practices, with studies indicating that a significant proportion of land can be classified as perfectly suited to maize production (Moshia et al., 2009). The dynamic nature of the classification system means that adjustments can be made as new data become available, reflecting changing environmental conditions (Habibie and Nurda, 2022). Although the FAO system is robust, its applicability may vary at different scales, as the results of localized studies may not translate directly into wider regions (Taati and Sarmadian, 2015); hence the need to precisely define the factors influencing land suitability is crucial to maintain the relevance and accuracy of the system (Habibie and Nurda, 2022).

Conclusion

This research aims to determine the characteristics and suitability classes of a lateritic toposequence for rain-fed maize cultivation in the Cameroon Western Highland. The main results show that the Summit and Footslope soils (Rhodic Eutric Nitisol (Ferric)) are currently marginal for rain-fed maize due to climatic and soil physical constraints. Soils (Gleyic Stagnosol, Pisoplinthic Plinthosol, and Stagnic Gleysol, respectively) of the basin with outflow, backslope, and endorheic basin are unsuitable for rain-fed maize, mainly because of poor aeration in the root zone and unsuitable topography as well as constraints linked to soil chemical fertility. However, adopting improved management operations could enable reclassifying the land into three potential suitability classes

Table 12. Evaluation of land and soil characteristics for maize cultivation at each of the five land units

Landscape and Soil characteristics	Land unit N°1: (P1) Rhodic Eutric Nitisol (Ferric)		Land unit N°2: (P4) Gleyic Stagnosol (Eutric)		Land unit N°3: (P2) Pisoplinthic Plinthosol (Eutric)		Land unit N°4 (P5) Eutric Nitisol		Land unit N°5: (P3) StagnicGleysol (Uterquic)	
	V	**Par V**	**V**	**Par V**	**V**	**Par V**	**V**	**Par V**	**V**	**Par V**
Topography (t)										
Slope (%) (l)	16.5	**60.77***	32	**38.5***	24	**48.57***	10. 5	**77.9***	>7	87.5
Wetness (w)										**12.5***
Flooding	FO	100	F2	**25***	FO	100	F0	100	F2	
Drainage	Very good	100	Poor and aeric	60	Good	100	Moderate	95	Poor	12.5
Physical soil characteristics (s)										
Texture	CL	100	CL	100	CL	95	CL	100	L	0
Coarse fragments (Volume %)	7.56	91.2	0	100	44.5	**50.5***	0	100	0	0
Soil depth (cm)	300	100	130	100	280	100	150	100	55	**65***
Soil fertility (f)										
CEC (meq/100g)	15.12	**60***	13.05	60	14.58	85	19.27	89.09	13.32	85
BS (%)	54.7	95.47	57.46	95.75	53.63	95.36	62.8	96.8	36.097	85.73
Organic carbon (%)	1.17	83.12	3.7	100	0.86	63.75	2.4	100	2.8	100
pH-H_2O	5.8	90	5.8	90	5.8	90	6.2	96	5.33	**53***
Salinity and sodicity (n)										
EC (mmhos/cm)	0.26	99.35	0.31	99.77	0.255	99.36	0.27	99.32	0.31	99.22
ESP (%)	0.7	99.56	3.23	97.98	2.348	98.53	0.63	99.6	0.289	99.81
Soil Index	24. 60		3. 048		10. 01		62. 04		0. 036	
Land index	10. 66	-	1. 32	-	4. 33	-	26. 87	-	0. 015	-
Actual Suitability class	S3, t	-	N2, tw	-	N1, t,s	-	S3, ct	-	N2, w	-

S3: Severe limitation, marginally suitable, low yield (40 - 60%); N1: very severe limitation, not recommended, but potentially suitable, unacceptable, very low yield (25 - 40%); N2: very severe limitation, not recommended, potentially not suitable, unacceptable yield (0 - 25%). *Most limiting soil parameter for yield; V= Value, Par V= parametric value; ESP: exchangeable sodium percentage

(Rhodic Eutric Nitisol (Ferric)) would become moderately suitable for maize, while Gleyic Stagnosol, Pisoplinthic Plinthosol, and Stagnic Gleysol, respectively, would become marginally suitable. The Eutric Nitisols (footslope) would be considered suitable. Potentially 47.3% of the land is marginal, 34.6% suitable and 18.07% is moderately suitable. A comparison of actual and potential maize yields on these five units of land, under both low and medium-input farming, shows that yields with low input levels increase from 0.9 (actual suitability) to 4 t/ha (potential suitability), while those with medium levels vary from 2.27 (actual suitability) to 5.8 t/ha (potential suitability). Yields of 4.5 to 6 t/ha are among the highest potential yields for improved maize varieties. This increase highlights the importance of using modest inputs to boost soil productivity for maize. These findings pave the way for future research and development of sustainable strategies for rain-fed agriculture, thereby contributing to responsible and effective agricultural development.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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