

Soil and Their Agronomic Suitability for Cocoa (*Theobroma cocoa L.*) in South Cameroon Plateau

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Abstract Cameroon is the world's fifth largest producer of cocoa (40,000 hectares of land), which is the main cash crop, employing 75% of farmers in central and southern Cameroon. However, low yields (370 kg. ha⁻¹) have been observed over time due to soil conditions, climate variability, and poor agricultural practices. To this end, a detailed characterization of the soils of the southern Cameroonian plateau will make it possible to optimize yields. Thus, the present study aims to characterize the soils of the Nkolandom locality in order to determine their suitability for cocoa cultivation. The study consisted of conducting a soil survey to open pits, whose horizons were characterized, and samples were taken for laboratory analysis of physicochemical parameters. The evaluation of the suitability of the soil for cocoa cultivation was carried out using the FAO method. Three (03) types of soil were identified: loose soils, hydromorphic soils, and soils on crust, which have morphological and analytical characteristics such as thick, sandy-clay to clayey texture, polyhedral structure, acidic to very acidic pH (4.1 to 5.8), low to moderate CEC content (7.28 to 27.76 cmol kg⁻¹), and low to very high organic matter content (1.4 to 9.1%). These soils have respective suitability classes S3/Nc,f, Nc,w and Nc,s due to climatic limitations, soil fertility, soil water conditions and soil physical characteristics. Ferrasols have a marginal to unsuitable aptitude due to climate (relative humidity in the driest month), where it is advisable to irrigate the soil in the dry season and use agroforestry systems (SAF), and soil fertility (pH and CEC), where it is more appropriate to correct the soil pH and use cover cropping systems (SCV). Gleysols and Ferrasols on armourstone have an uncorrectable inaptitude due to the waterlogging of these soils and the presence of armourstone where cocoa cannot move its roots well.

Keywords: South Cameroonian Plateau, morphological characterisation, physico-chemical characterisation, cultural aptitudes, cocoa, yield

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1. Introduction

Population growth has raised concerns about the ability of agriculture to ensure future food security, and the global effects of climate change suggest new threats to the sustainability of agricultural systems [1,2,3]. According to recent estimates, global agricultural production should increase by 70% to meet the food needs of a world that will have around 9.1 billion inhabitants in 2050 [4]. One of the biggest challenges facing developing countries is producing enough food, in sufficient quantity and quality, to meet population demand. To this end, it is also necessary to ensure that the fertility of land resources is maintained and improved to increase productivity [5]. In this way, increasing agricultural production in the future depends not only on the availability of land and the

necessary water resources, but also on in-depth and detailed knowledge of the soil [4]. In addition, this knowledge involves characterising the soil material, whose spatio-temporal variability conditions its fertility, the choice of crops and its cultivation aptitudes. For African countries, and Cameroon in particular, cocoa and its by-products are an important source of income that has an impact on GDP [6,7]. However, in Cameroon, cocoa is grown on small farms, with yields falling over the years, with an average production per hectare estimated at 375 kg/ha/year, lower than the average production in other African countries such as Côte d'Ivoire (12,500 kg/ha/year), Ghana (450 kg/ha/year) and Nigeria (390 kg/ha/year) [6,7]. Furthermore, cocoa farming faces enormous problems, including climate change and poor farming practices, which contribute to the loss of soil fertility and lower yields [8,9]. Furthermore, the lack of in-depth and detailed knowledge of soils in relation to

their variability and their associated agricultural potential remains a very serious limitation that violates the sustainable management of these soils; hence the interest of this study, whose objective is to characterise the soils of the locality of Nkolandom located in the humid forest zone of southern Cameroon, one of the cocoa production basins in Cameroon, in order to determine their suitability for cocoa cultivation.

2. Materials and Methods

2.1. Study Area

The study was carried out in the locality of Nkolandom on the South Cameroon plateau (Figure 1). It is characterized by a Guinean-type equatorial climate with four seasons, average annual rainfall of around 1,500 to 2,000 mm yr⁻¹ and average annual temperature of around 25°C (Figure 2) [10]. The vegetation is composed of mosaic of savannah and semi- deciduous forest in the north and evergreen forest in the south, with a Biafran type in the south-west and a Congolese type in the south-east [11,12]. The southern Cameroon plateau is also characterized by an altitude of between 600 and 900 m.

There are 4 main types of geomorphological landscape [13]: mountain massifs near the western edge of the plateau, a large floodplain in the upper Nyong watershed and extensive, very blunt interfluvies [14]. Geologically, the South Cameroon plateau rests on a granite-gneiss bedrock belonging to the lower Precambrian formations. These are the pyroxene orthogneisses and pyroxene granodiorites that make up the calco-Magnesian complex of southern Cameroon [15]. Southern Cameroon is the domain of alitic ferralitic soils, orthic ferralitic soils, yellow and red ferralitic soils, hydromorphic soils, crude mineral soils, soils of little evolution and various types of soil association [16,17,18].

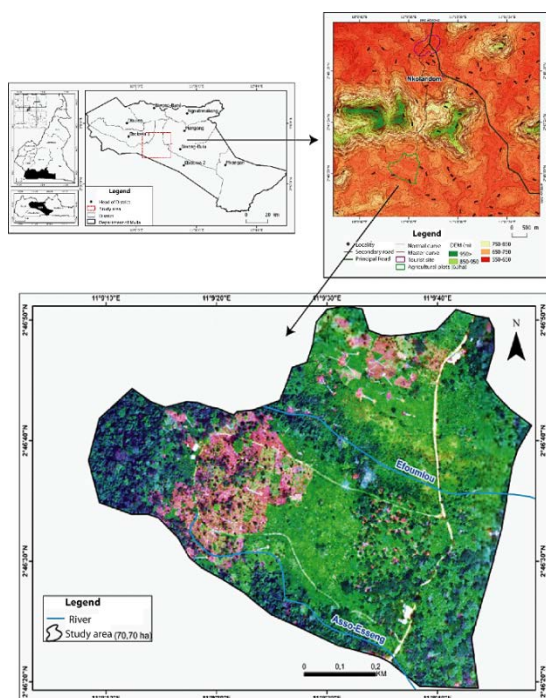


Figure 1. Location of study area

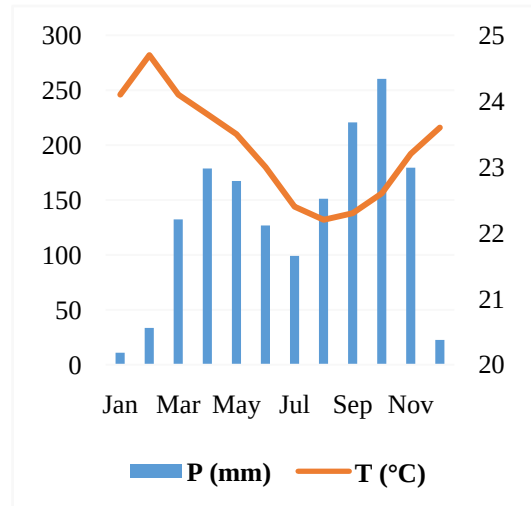


Figure 2. Ombrothermal diagram (<https://power.nasa.gov>)

2.2. Field and Laboratory Work

The fieldwork focused mainly on soil prospecting using a 1:200,000 topographical map, and consisted of landscape analysis, hand augering, hand sinking and morphostructural characterisation of the soil pits and taking soil samples.

The soil survey was carried out using a hand auger on a grid of 100 m by 150 m for some test points and 25 m by 50 m for others, in order to obtain very detailed information on the ground. With the exception of obstacles such as coarse elements, the water table, rock fragments and armour, all the test pits were 1.20 m deep, corresponding to six (06) sections of soil core taken at 20 cm intervals. A meticulous description of these sections enabled us to identify the soil series within which representative pedological pits were sunk to a depth of 1.20m. Once the soil profiles had been described, samples of disturbed and undisturbed soil were taken and sent to the laboratory for physico-chemical soil analysis.

These analyses include granulometric fraction analysis (Robinson pipette), organic carbon analysis using the Walkley and Black method [19] where

$$MO = CO \times 1.724 \quad (1)$$

Cation exchange capacity (CEC) and exchangeable bases by extraction, base saturation

$$V(\%) = \left(\frac{S}{T} \right) \times 100 \quad (2)$$

(S = sum of exchangeable bases and T = cation exchange capacity of the soil), total nitrogen using the Kjeldahl method, assimilable phosphorus using the Bray II method, pH using a pH meter, alkalinity and electrical conductivity (EC) (conductivity meter).

Soils were classified according to the WRB [20].

2.3. Soil Evaluation Method

Climatic assessment (c) was carried out using the method of [21] on climatic data over a 30-year period (from 01/01/1992 to 31/12/2021), downloaded from the NASA website (<https://power.nasa.gov>). It consisted of calculating the average rainfall (maximum, average and

monthly) over 30 years and the average temperatures (maximum, minimum and average), evapotranspiration, relative humidity and insolation over ten (10) years. There are in fact three methods of climatic evaluation, namely the lowest class method, the number and degree of limitation method and the parametric method leading to the determination of the climatic index noted IC and the adjusted climatic index noted CR.

In addition, three pedological evaluation methods, namely the lowest class method, the number and degree of limitations method and the parametric method, led to the determination of the pedological index noted IP and the soil index noted IT [22] for rainfed agriculture, making it possible to classify six (06) aptitude classes with values for each interval. These are S1-0 (95-100): very high suitability, no limitations, S1-1 (85-95): high suitability, slight limitations, S2 (60-85): average suitability, moderate limitations, S3 (40-60): marginal suitability, severe limitations, N1 (25-40): current unsuitability, very severe but correctable limitations and finally N2 (0-25): permanent unsuitability, very severe limitations that cannot be corrected with the current level of knowledge. The edaphic parameters used in the assessment are topography (t), water conditions (w), physical conditions (s), chemical conditions (f) and soil salinity and alkalinity (n).

3. Results

3.1. Soil Type

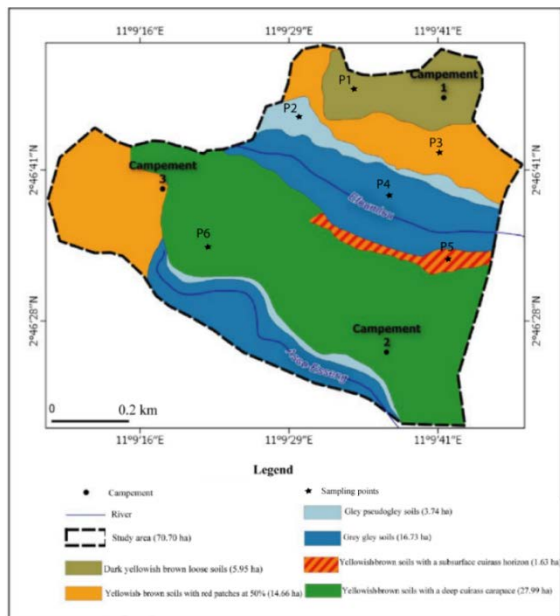


Figure 3. Soil map of study site

The soil survey identified six (06) homogeneous soil units within which six wells were sunk, including (1) loose dark yellowish-brown soils (5.95 ha) occupying 8% of the study plot and located to the north-east of the plot. (2) Yellowish-brown soils with 50% red patches (14.66 ha) occupying 21% of the study plot and located to the north-east and west of the plot. (3) Grey soils with pseudogley (3.74 ha), occupying 5% of the study plot and located in the centre and south of the plot. (4) Grey Gley soils (16.73 ha) occupying 24% of the study plot and

located in the centre and south of the plot. (5) Yellowish-brown soils with a sub-surface leathery horizon (1.63 ha) occupying 2% of the study plot and located to the east of the plot. (6) Yellowish-brown soils with deep armour (27.99 ha) occupying 40% of the study plot and extending from the east to the west of the plot (Figure 3). These soils have been grouped into three main types: loose soils, hydromorphic soils and armourstone soils.

3.2. Morphological of the Soils Studied

The morphology of the soils studied shows (Plate 1) that the loose dark yellowish-brown soils are dark yellowish brown, loose and 250 cm deep, and the soil profile comprises three (03) horizons with a clayey-sandy to clayey texture overall, with a fine lumpy structure at the surface and a polyhedral structure at depth, with a compactness that increases with depth. On the other hand, the yellowish-brown soils with red patches (50%) have a yellowish-brown soil profile with red patches (50%), 250cm deep. It comprises three horizons with a clayey-sandy to clayey texture, with a fine lumpy structure at the surface and a polyhedral structure at depth, with a compactness that increases with depth. There are red spots (10R4/6) that are not very coherent, millimetre-sized and rounded in shape, the percentage of which increases with depth, reaching 50% of the volume of the horizon from 230cm upwards. However, the pseudogley soils are shallow (60cm), and comprise 3 horizons with a silty-clayey to sandy-clay texture overall, with a medium lumpy structure at the surface and polyhedral at depth, moderately compact at the surface and compact at depth, and the presence of rust-coloured hydromorphic stains (7.5YR5/8) estimated at 20 to 40%. Similarly, the gley soils are also shallow (40cm), and comprise three horizons with a silty-clay to clayey texture, a medium lumpy structure at the surface and polyhedral at depth, slightly compact at the surface and compact at depth, and the presence of patches of yellowish-red hydromorphy (5YR5/6) estimated at 30% to 50% (Plate 1).

In addition, the subsurface yellowish-brown soils with a cuirass horizon have a yellowish-brown soil profile with a cuirass block appearing at less than 120 cm, averaging 90 cm in depth and comprising three horizons forming two groups; This is a shallow, superficial unit (35cm) with a silty clayey-sandy to clayey texture, with a fine to polyhedral lumpy structure, not very compact at the surface and compact at depth, with indurated nodules of a dark red to mottled colour (2, 5YR4/8) on the surface and red (2.5 YR3/6) on the inside and of millimetre size representing 20% of the volume of the horizon, while the lower part is yellowish brown with small dark red to matt indurated nodules in places. It rests on a block of armour. And finally, Yellowish brown soils with deep armour carapace, which are yellowish brown soils with deep armour carapace, their soil profile is 300 cm deep and comprises three horizons with a clayey-sandy to clayey texture overall, with a fine lumpy structure on the surface and a polyhedral structure at depth, the compactness increases with depth, with millimetre-sized quartz grains (5-10%) and coherent, rounded red spots (2.5YR5/8) of millimetre to centimetre size (40%). The top of the armour is visible at 360cm after augering.



Plate 1. Dark yellowish-brown loose soils (a), yellowish-brown soil profile with red patches at 50% (b), pseudogley soils (c), gley soils (d), yellowish-brown soils with a subsurface cuirass horizon (e), yellowish-brown soils with a deep cuirass carapace (f)

3.3. Physico-Chemical Characteristics of the Soils Studied

In physico-chemical terms (Table 1), the loose dark yellowish brown soils and the yellowish brown soils with red patches at 50% have a clayey-sandy texture at the surface and clay at depth, with a low clay CEC at the surface and moderately high at depth varying from 0.03 to 0.33, with a moderately acid pH at the surface and acid pH at depth varying from 5.8 to 4.1 ; hydromorphic soils with pseudogley and gley have a silty-sandy-clay texture at the surface and clay at depth, with a low clay CEC from surface to depth varying from 0.07 to 0.02, with an acid pH from surface to depth varying from 4.9 to 4, 4 and yellowish-brown soils with a subsurface cuirass horizon and yellowish-brown soils with a deep cuirass shell have a clayey-sandy texture at the surface and clay at depth, with a relatively low clay CEC from the surface to depth, with a moderately acid pH at the surface and acid pH at depth ranging from 5 to 4.2.

The highest clay content is 56.54% in horizon 3 of profile 2, and the lowest is 16% in horizon 1 of profile 4. The highest sand content is 55.54% in horizon 1 of profile 6, and the lowest content is 4% in the last two horizons of profile 1. Silt content remains constant along all profiles (Figure 4).

The organic matter content ranges from 0.81% to 5.27% in profiles 6 and 3 respectively, while the average total nitrogen content drops drastically in all profiles, from

a low of 0.6g kg in profile 2 to a high of 3.69 g kg in profile 6. However, the C/N ratio increases antagonistically in the deeper horizons, with a low value of 0.59 in profile 4 and a high value of 4.70 in profile 5 (Figure 5).

K has the highest content at 18.53 cmol kg⁻¹ in horizon 1 of profile 6, followed respectively by Ca at 11.36 cmol kg⁻¹ in horizon 1 of profile 5, then Mg at 3.44 cmol kg⁻¹ in horizon 1 of profile 2 and Na at 1.21 cmol kg⁻¹ in horizon 3 of profile 6, which is fairly constant along the profiles (Figure 6).

The sum content of exchangeable bases, ranging from 1.78 to 13.88 cmol kg⁻¹ in profiles 6 and 5 respectively, decreases from surface to depth in all soil profiles. The highest CEC content (36.38 cmol kg⁻¹) is observed in horizon 1 of profile P6, while the lowest content (7.28 cmol kg⁻¹) is recorded in horizon 2 of profile P5 (Figure 7).

The lowest levels of exchangeable phosphorus are found in profile P6, at 5.67 mg kg⁻¹, while the highest levels are found in profile P3, at 68.35 mg kg⁻¹. The lowest values for the percentage of exchangeable sodium are 0.03% in horizon 2 of profile 1, and the highest values are 2.27% in horizon 2 of profile 2. Electrical conductivity remains constant along the soil profiles (Figure 8).

3.4. Soil Classification

Dark yellowish brown loose soils correspond to umbric ferralsols (clayic, eutric, humic); yellowish brown soils with red patches at 50% correspond to plintic ferralsols

(clayic, eutric, humic); pseudogley soils correspond to oxygleyic gleysols (clayic, humic); Gley soils correspond to reductigleyic gleysols (siltic, folic, limonic); subsurface yellowish brown armoured soils correspond to duric ferrasols (aric, dystric, saprolithic) and deep yellowish brown armoured soils correspond to pisoplintic ferrasols (clayic, eutric, humic).

3.5. Land Suitability for Cocoa Cultivation

3.5.1. Climatic Evaluation

The climate of the Nkolandom locality has a marginal suitability of S3 (54) for cocoa cultivation with a severe limitation due to the relative humidity of the driest month and the length of the dry season, which is the month when rainfall is less than half evapotranspiration. (Table 2).

3.5.2. Pedoclimatic Assessment for Cocoa Growing

Figure 9 and the following Table 3 show that umbric FERRASOLS (clayic, eutric, humic), plinthic FERRASOLS (clayic, eutric, humic) and pisoplintic FERRASOLS (clayic, eutric, humic) have marginal to unsuitable suitability for cocoa cultivation due to climatic limitations (relative humidity in the driest month) and soil fertility, more specifically low CEC content and acid pH (S3/Nc, f), the oxygleyic GLEYSOLS (clayic, humic) and the reductigleyic GLEYSOLS (siltic, folic, limonic), present an inaptitude (Nc,w) with very severe uncorrectable limitations, due to the always permanent waterlogging (hydric condition of the soil). The duric FERRASOLS (aric, dystric, saprolithic), on the other hand, are unsuitable (Nc,s) with very severe uncorrectable limitations, due to the presence of subsurface armour (physical characteristics of the soil) respectively.

Table 1. Soil Physico-Chemical Data

Sols	UH 1			UH 2			UH 3			UH 4			UH 5			UH 6		
Soils	H1	H2	H3	H1	H2	H3	H1	H2	H3	H1	H2	H3	H1	H2	H3	H1	H2	H3
Deph (cm)	0-20	20-80	80-250	0-20	20-90	90-250	0-10	10-20	20-40	0-10	10-45	45-60	0-10	10-35	35-90	0-20	20-130	130-300
Sandy (%)	51	4	4	43	41.8 2	35.6 8	55.6 8	37.3 9	33	69	53.6 1	33	49.2 5	39.6 1	35	55.5 4	37.8 2	35
Clay (%)	37	53	48	53	50.4 6	56.5 4	29.0 4	44.6 1	49	16	28.5 4	49	40.6 8	52.6 1	57	36.5 4	56.4 6	57
Silt (%)	12	4	12	4	7.71	7.78	15.2 8	18	18	15	15.8 6	18	10.0 7	7.78	8	7.79	5.71	8
BD (g.cm ⁻³)	1.1	0.95	1.25	0.86	1.35	1.3	0.97	0.98	1.07	0.86	1.25	1.38	1.11	1.17	1.27	0.96	0.93	1.2
pH	5.8	4.1	4.4	4.6	4.3	4.8	4.9	4.8	4.4	4.6	4.5	4.6	5	4.3	4.4	4.6	4.3	4.2
OC (%)	2.39	3.37	1.68	2.17	2.55	1.63	4.19	2.72	2.44	1.9	2.17	1.74	5.27	1.85	1.63	4.4	1.3	0.81
OM (%)	4.12	5.81	2.9	3.75	4.4	2.81	7.22	4.69	4.22	3.28	3.75	3	9.1	3.18	2.81	7.59	2.59	1.4
TN (g.kg)	2.66	0.84	0.7	3.15	0.91	0.63	1.33	1.29	0.94	3.36	0.7	1.33	1.12	1.08	1.15	3.69	1.01	0.84
C/N	9	40.1 6	24.1	6.91	28.1	25.6 1	31.5	21.0 1	25.9 1	5.66	30.7 9	13.0 2	47.1 3	17.0 5	14.1 3	11.9 2	12.8 6	9.71
Ca ²⁺	6.08	1.04	6	8.64	2.48	4.64	1.04	1.68	1.12	0.16	0.72	0.48	11.3 6	0.96	0.32	8.72	0.64	0.48
Mg ²⁺	1.84	1.66	0.44	3.44	2.08	0.72	3.22	1.84	0.32	2.48	1.84	2.48	2.24	0.64	2.08	2.16	1.36	0.08
K ⁺	1.66	1.08	1.08	0.61	1.08	1.35	0.01	0.28	1.08	3.69	0.01	0.01	0.01	0.01	0.01	18.5 3	0.01	0.01
Na ⁺	0.27	0.27	0.39	0.27	0.39	0.39	0.27	0.27	0.53	0.53	0.27	0.27	0.27	0.16	0.16	0.16	0.16	1.21
SEB	9.86	3.99	7.87	12.9 7	6.03	7.11	4.52	4.07	3.05	6.86	2.82	3.24	13.8 8	1.78	2.58	29.6	2.18	1.78
CEC clay	27.7 6	13.7 6	14.9 6	16.6 4	13.3 6	17.6 8	16.5 6	14.6 4	12.9 6	15.5 2	14.0 8	10.9 2	15.9 2	7.28	13.5 2	36.3 8	8.17	14.6 4
Pass II (ppm)	17.9 8	10.4 2	12.2 7	28.7 4	13.0 1	9.38	28	32.9 7	68.3 5	13.0 1	10.7 1	27.3 3	17.4 6	8.04	8.26	26.5 1	7.82	5.67
CE (mS.c m ⁻¹)	0.23	0.07	0.03	0.5	0.08	0.06	0.32	0.06	0.11	0.27	0.04	0.03	0.3	0.06	0.06	0.18	0.09	0.04
PSE	0.08	0.03	1.53	1.89	2.27	1.29	1.16	1.4	0.42	1.18	0.32	0.05	0.19	0.6	0.94	0.54	0.29	0.66

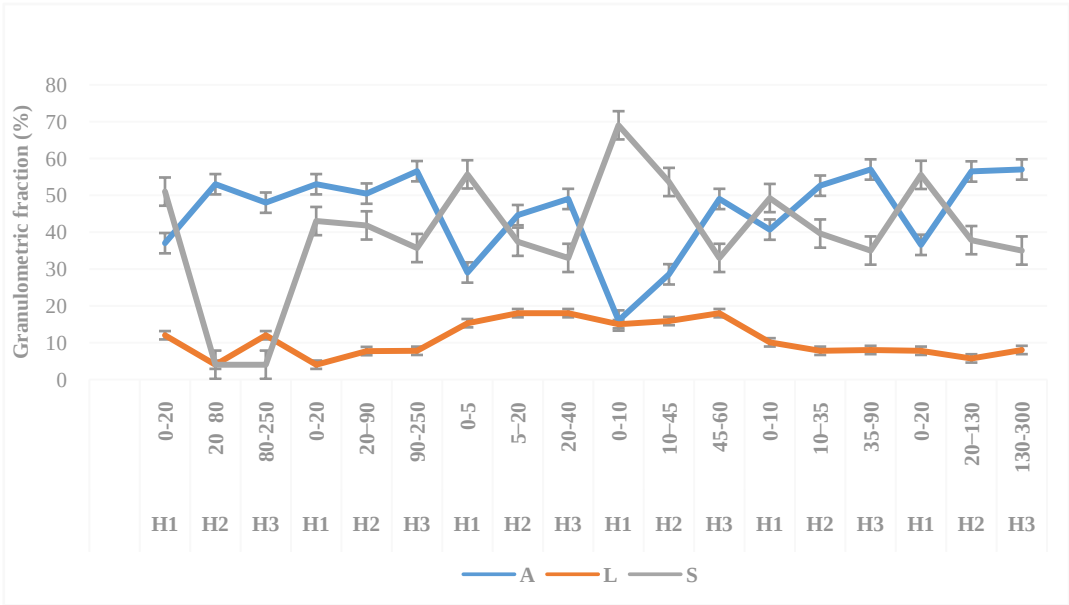


Figure 4. Variation in clay, silt and sand content of soils

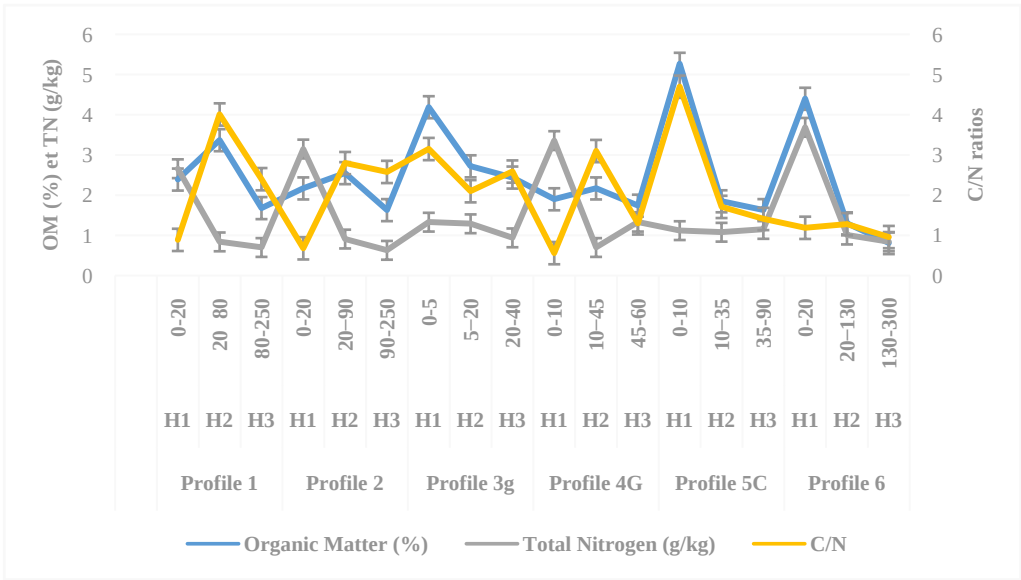


Figure 5. Variation in OC, TN and C/N ratios in soils

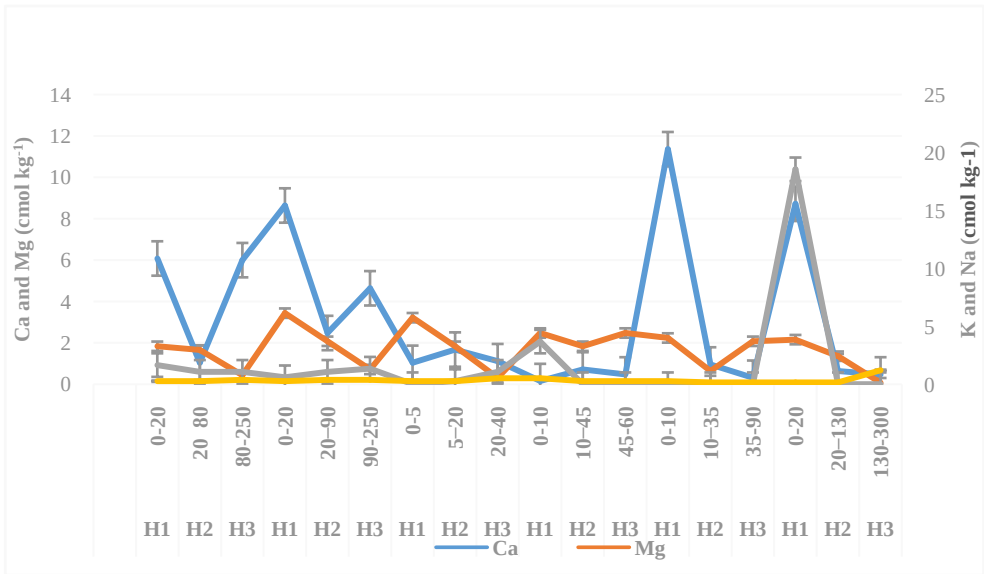


Figure 6. Distribution of exchangeable bases in soils

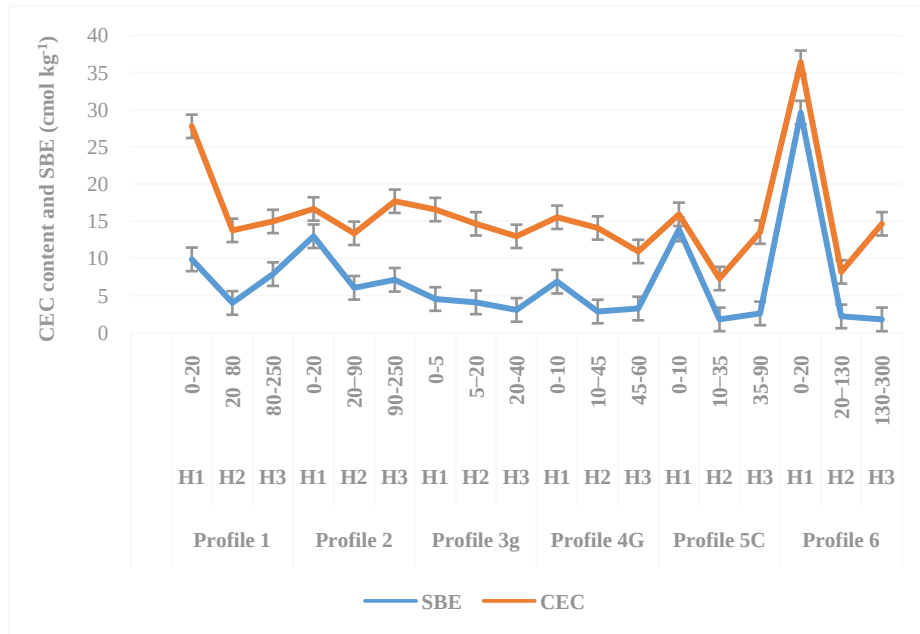


Figure 7. Distribution of exchangeable bases in soils

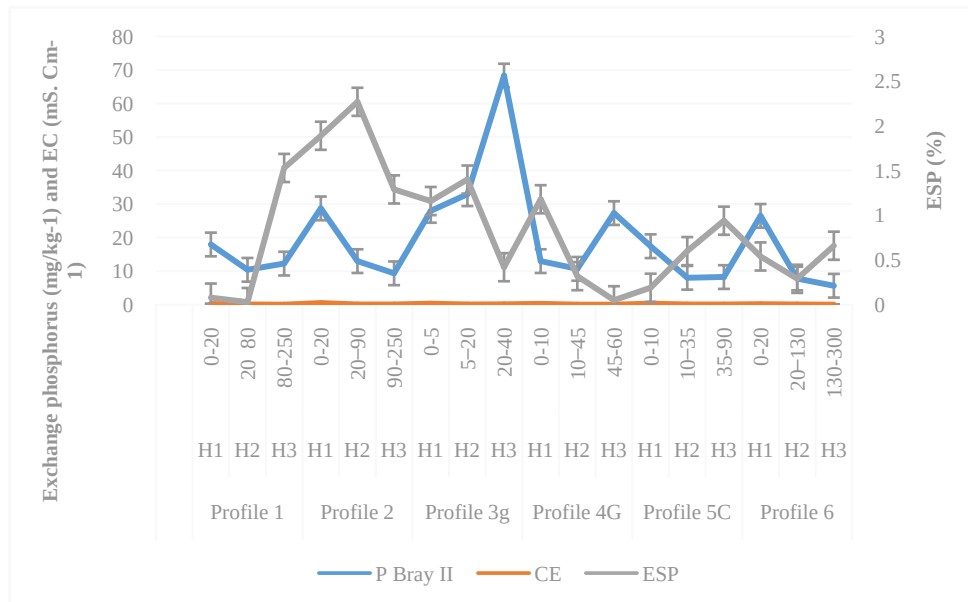


Figure 8. Variations in assimilable phosphorus, electrical conductivity and percentage of exchangeable sodium in soils

Table 2. Climatic Evaluation of Cocoa Trees (*Theobroma cacao*)

Climatic characteristics	Values	Classes	Number and degree of limitations	Values Parametric
Average annual precipitation (mm)	1553.03	S2	2	79.1
Length of dry season (months or P less than ETP/2)	3	S2	2	60
Average annual temperature (°C)	23.3	S1-1	1	88.8
Maximum annual mean temperature	32.3	S2	2	72.5
Minimum annual mean temperature	16.6	S1-1	1	91
Relative humidity driest month	78.8	S3	3	54
Lowest class method: S3				
Number and degree of limitation method: S3				
IC= 23.7				
CR= 37.8				

Table 3. Pedoclimatic Evaluation of the Cocoa Tree (*Theobroma cacao*)

Soil s	P1			P2			P3			P4			P5			P6		
EI	Valu e	Clas s	PV	Valu e	Clas s	PV	Value	Clas s	PV	Value	Clas s	PV	Valu e	Clas s	PV	Valu e	Clas s	PV
Topography (t)																		
Slope (%)	4	S1-0	95	4	S1-0	95	2	S1-0	97.5	2	S1-0	97.5	4	S1-0	95	4	S1-0	95
Soil Water conditions (w)																		
F	Fo	S1-0	100	Fo	S1-0	100	F1	S3-3	50	F1	S3-3	50	Fo	S1-0	100	Fo	S1-0	100
D	Good	S1-0	100	Good	S1-0	100	Moderate	S2-2	70	Moderate	S2-2	70	Good	S1-0	100	Good	S1-0	100
Physical Characteristics of the soil (s)																		
T	A	S1-0	100	A	S1-0	100	A	S1-0	100	SAL	S1-0	100	A	S1-0	100	A	S1-0	100
CF (%)	0	S1-0	100	0	S1-0	100	0	S1-0	100	0	S1-0	100	30	S2-2	70	0	S1-0	100
SD (cm)	>250	S1-0	100	>250	S1-0	100	40	N2	24	60	S3-3	44	90	N2	56	>250	S1-0	100
CaCO ₃ (%)	0	S1-0	100	0	S1-0	100	0	S1-0	100	0	S1-0	100	0	S1-0	100	0	S1-0	100
Gypse (%)	0	S1-0	100	0	S1-0	100	0	S1-0	100	0	S1-0	100	0	S1-0	100	0	S1-0	100
Soil fertility characteristics (f)																		
CEC Clay	18.82	S1-1	88	15.89	S2-2	85	14.72	S2-2	84	13.50	S2-2	80	12.24	S2-2	78	19.73	S1-1	89
BS (%)	39.08	S1-1	85	54.48	S1-0	95	26.26	S2-2	65	31.41	S2-2	70	43.59	S1-1	90	40.27	S1-1	89
OC (%)	2.3	S1-0	100	2.1	S1-0	100	4.1	S1-0	100	1.9	S1-1	95	5.2	S1-0	100	4.6	S1-1	100
Hp (SH (0-30 cm))	5.8	S2-2	62	4.6	S3-3	50	4.9	S3-3	52	4.6	S3-3	50	5	S3-3	55	5.5	S2-2	60
Salinity et sodicity																		
EC	0.6	S1-0	100	0.2	S1-0	100	0,1	S1-0	100	0.1	S1-0	100	0.1	S1-0	100	0.1	S1-0	100
PES	0.5	S1-0	100	1.8	S1-0	100	0,1	S1-0	100	0.5	S1-0	100	0.5	S1-0	100	0.4	S1-0	100
EI		S3/N	20		S3/N	15		N	1		N	2		N	6		S3/N	19

EI: Evaluation Index, PV: Parametric Value, F: Floods, D: Drainage, T: Texture, CF (%): Pourcentage coarse fragments, PS (m): Soil depth, CECa (méq.100g⁻¹): Cation exchange capacity of clay, BS (%): Base Saturation, CO (%): Organic Matter, Hp (SH): Hydrogen potential of the surface horizon at the base, EC (mmhos.cm⁻¹): Electrical Conductivity, PES (%): Percentage of Exchangeable Sodium, EI: Earth Inde

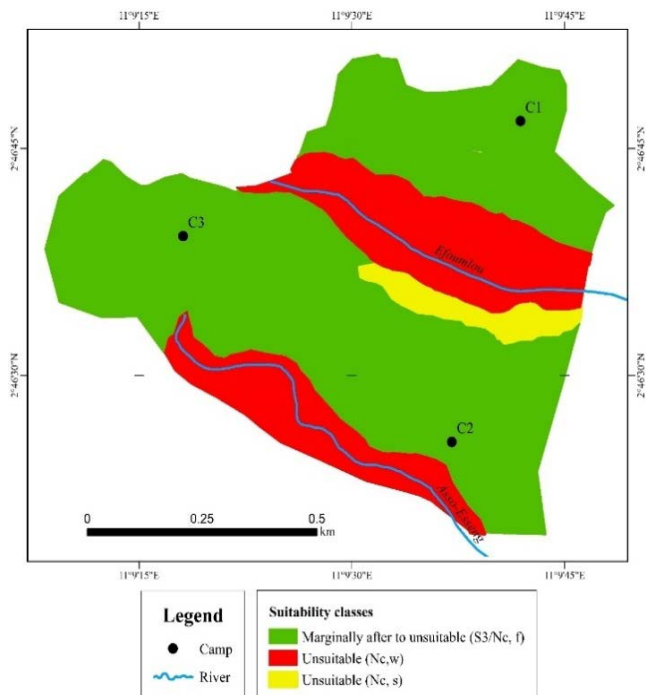


Figure 9. Suitability map for rainfed cocoa cultivation

4. Discussion

4.1. Nature Des Sols

In the bimodal rainforest zone, the soils are generally Ferralsols and Gleysols [23]. These soils are located at high altitudes, on plateaux and depressions. Specifically, Ferralsols are thick, dark yellowish-brown in colour, with a sandy-clay to clay texture, a polyhedral structure and red patches (35 and 50%) embedded in a yellowish matrix with blocks of subsurface armour. In general, these are soils developed on acid rock, where their overall yellowish-brown colour is due to the presence of iron oxyhydroxide, particularly goethite [23,24]. Studying the differential weathering of granite in humid tropical zones, obtained results showing very thick soils with a sandy texture. In addition, several studies of soils in the humid forest zone also found that they have acidic characteristics attributable to the acidic parent rock on which the soils developed [17,18,23,24,25,26]. Gleysols, on the other hand, are thinner, 40 to 60 cm deep, with a clayey to silty-sandy texture, a massive structure and patches of hydromorphy varying from 30 to 50%. Hydromorphic

staining is observed in these lowland soils and reflects oxidation-reduction conditions [17,27,28,29].

Physico-chemically, Ferralsols are very acidic soils (4.40), with a very low CEC (7.28 cmol kg⁻¹), a high sum of bases (13.88 cmol kg⁻¹) and an average organic matter content (9.1%). These values were also observed by [30] and would be due to the leaching of exchangeable bases under the high precipitation conditions of the equatorial climate. Similar values were also noted by [23,30,31]. These thick soils allow good permeability and infiltration of water that can be used by plants [23,31]. In addition, the low CEC content is justified by a mineralogical paragenesis dominated by kaolinite [17,18,25,32,33].

4.2. Agronomic Potential of Soils

The soils studied for cocoa cultivation show marginal suitability classes for ferralsols (S3/Nc,f) due to climate (relative humidity in the driest month) and soil fertility (pH and CEC); and unsuitable for gleysols (Nc,w) and ferralsols on cuirasses (Nc,s), due respectively to climate, soil water conditions and soil physical constraints. Similar studies have shown marginal to unsuitable suitability classes for perennial crops, in this case coffee [34].

In the southern plateau of Cameroon, the Guinean sub-equatorial climate is dominant, characterised by high humidity, favoured by the presence of large bodies of water, such as the Congo River and the Atlantic Ocean. In addition, frequent and abundant rainfall helps to maintain humidity in the soil and air, creating an unfavourable environment for cocoa growth. This climate also brings high temperatures, which encourages evaporation and the formation of water vapour [35,36].

This climatic constraint could be corrected by installing a sprinkler irrigation system and plant cover systems (SCV), specifically creeping grasses [21,37,38]. Similarly, the low CEC observed by several authors in ferralsols [17,18,24,22,27] is a limiting factor for fixing elements in the absorbent complex, which is the larder for plants, especially cocoa [21,23,33,38]. However, the agronomic constraint on cocoa due to low CEC could be improved by adding an organic amendment that would replenish the clay-humus complex with nutrients, whereas the acid pH would make phosphorus unavailable to cocoa, which could lead to phosphorus deficiency [21,23,33,38]. This constraint due to soil acidity could be corrected by the use of mineral amendments such as agricultural lime and dolomite.

Gleysols and Ferralsols on armourstone show uncorrectable unsuitability (Nc,w) and (Nc,s) for cocoa. Similar suitability classes have also been obtained for perennial crops, notably coffee in the forest zone [34]. This unsuitability is justified, on the one hand, by the permanent waterlogging likely to asphyxiate the cocoa tree roots, and on the other hand, by the presence of the armoured horizon, which constitutes a physical constraint to the rooting of the cocoa tree [17,18,28,29].

5. Conclusion

The study identified two main groups of soil references, including ferralsols, which are characterised by a dark yellowish-brown colour, a clayey-sandy texture, a very

acid pH (4.40), a very low CEC (7.28 cmol kg⁻¹) and an average organic matter content (9.1%).

Gleysols are characterised by a clayey to silty-clayey-sandy texture, with a massive structure and patches of hydromorphy varying from 30 to 50%, an acid pH (4.6), a high CEC (16.56 cmol kg⁻¹) and an average organic matter content (7.22%).

In the end, three suitability classes were identified, the marginal suitability class (S3/Nc,f) for ferralsols due to climate (relative humidity in the driest month) and soil fertility (pH and CEC); the unsuitable class (Nc,w) for gleysols and the unsuitable class (Nc,s) for ferralsols on armourstone, due respectively to climate, soil water conditions and soil physical constraints.

Once the environmental, physical and chemical constraints of the soils have been identified and the best possible management has been proposed, organic and mineral amendments need to be applied to the soil, with a view to restoring and maintaining the fertility of these soils in order to increase cocoa yields in the Southern Plateau of Cameroon. In addition to good monitoring and maintenance of the plantation, as well as scrupulous compliance with the technical itinerary and uniformity of cocoa varieties for the land units inventoried, it would be very interesting to take the research a step further by carrying out an evaluation of the suitability of the land for cocoa cultivation in an irrigated system, coupled with trials of vegetation cover systems (SCV), more specifically creeping grasses.

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