Journal of Geoscience and Environment Protection, 2018, 6, 15-33
http://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Soil Properties and Land Capability Evaluation in a Mountainous Ecosystem of North-West Cameroon

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How to cite this paper: Azinwi Tamfuh, P., Temgoua, E., Wotchoko P., Boukong, A. and Bitom D. (2018) Soil Properties and Land Capability Evaluation in a Mountainous Ecosystem of North-West Cameroon. *Journal of Geoscience and Environment Protection*, **6**, 15-33.
https://doi.org/10.4236/gep.2018.67002

Received: April 1, 2018
Accepted: June 25, 2018
Published: July 6, 2018

Abstract

Up to date, tropical mountainous ecosystems still lack in depth information on soil and environmental characteristics which are major factors limiting optimum crop production. The objective of this work was to study soil characteristics and to evaluate the land capability level for the production of some common tropical crops in mountainous ecosystem soils of North West Cameroon. Soil sampling was done following a randomized complete block design (RCBD) with four replications for three topographic positions (upslope, midslope and footslope) and at two depths (0 - 20 cm and 20 - 100 cm). It was completed by standard laboratory analyses. The fertility capability classification (FCC) system enabled to identify soil limitations and to classify soils into FCC units. Land and climate were evaluated by simple limitation and parametric methods. Globally, the soils were dark-colored, sandy clayey to clayey, compact and very acidic (pHH_2O = 4.3 - 5.8). The organic matter (3.7% - 5.1% dry matter), total nitrogen (0.08% - 0.56%) and available phosphorus (22.1 to 30.9 mg·kg^{-1}) recorded for the 0 - 20 cm depth then reduced with depth but midslope values were also lower. The C/N ratio varied between 9 and 45. Low C/N values appeared mostly in 0 - 20 cm depth at the upslope and downslope soils and subsurface soils of midslope position. Exchangeable Ca was very low to low (1.43 - 3.6 cmol + kg^{-1}), Mg was very low to low (0.39 - 1.5 cmol + kg^{-1}), K was low to medium (0.2 - 0.54 cmol + kg^{-1}) and Na was very low (<0.1 cmol + kg^{-1}). The sum of exchangeable bases was very low (3.02 - 5.19 cmol + kg^{-1}), cation exchange capacity was low to moderate (8.60 - 25.6 cmol + kg^{-1}) and base saturation was very low to low (19.27% - 36.97%). Leaching of bases under heavy rainfall is a major cause of soil acidification under humid topical ecosystems. The Ca/Mg/K ratio was unbalanced and Mg was the most relatively concentrated base in all the soils. There was a clear variation of most of the soil properties along the slope and with depth. The soils were classified in the FCC system as aek for the upslope soils, Caek for the midslope soils and Cagk for the footslope soils. The principal limitations to production of huckleberry, beans, maize and potatoes were heavy rainfall, wetness, steep slope, soil texture/structure and low soil fertility. These constraints might be overcome by farming at the end of the raining season, contour ploughing, terracing, fertilization and liming.

Keywords

Land Evaluation, Fertility Capability Evaluation, Nutrient Status, Mountainous Ecosystem, Bafut, North-West Cameroon

1. Introduction

Mountainous ecosystems are quite widespread in the intertropical zone [1] [2] [3]. Soils in such ecosystems are often very vulnerable due to demographic pressure associated with environmental conditions like rainfall and topography [4]. This explains the poor agricultural yields, the extension of cultivated areas and the movement of populations towards more fertile lands in the upper part of the mountain formerly reserved for pastoral nomadism and market gardening [4] [5] [6]. Here, slope plays an essential role in increasing the diversity of soil cover [7] [8] [9]. Soil loss from land surfaces due to erosion is thus widespread and affects crop productivity in such natural mountainous ecosystems [10] [11] [12] [13] [14]. The impact of soil erosion is intensified where often more than half of the surface soil is carried away as the water splashes downhill into valleys and waterways [9] [14]. This leaves the soil barren and fully exposed to rain and wind forces of erosion [14]. The phenomenon is especially widespread in developing countries where populations are large, and agricultural practices are often inadequate to protect topsoil. In the tropics, one of the major factors limiting optimum crop production is the lack of detailed information on soil and land characteristics [9]. Soil fertility decline due to overcultivation has led to the colonization of hill slopes in the north western highlands of Cameroon [15] [16]. Such published works are quite localised mostly in the Bambouto Mountains [4] [5] [17]-[23] and the other Cameroonian highlands are yet to be investigated in detail. There is therefore a need for compilation of baseline information on other mountainous ecosystem soils of Cameroon in an attempt to better manage such ecosystems. The main aim of the present study was to characterize the soil and to evaluate the land capability for the production of some common tropical crops in some mountainous ecosystem soils in North-West Cameroon. The results obtained will provide data to farmers on the management strategies to be adopted on such soils for optimum food productivity.

2. Materials and Methods

2.1. Study Area Description

Bafut Sub-Division covers an area of about 340 km^2. It is situated about 20 km northwest of Bamenda town (north of Mezam Division, North West Region) between latitude 06˚05'N - 06˚11'N and longitude 09˚58'E - 10˚11'E (Figure 1) [24]. The mean annual precipitation is 2657.2 mm, with a long rainy season from March to November and a dry one from December to February. The mean

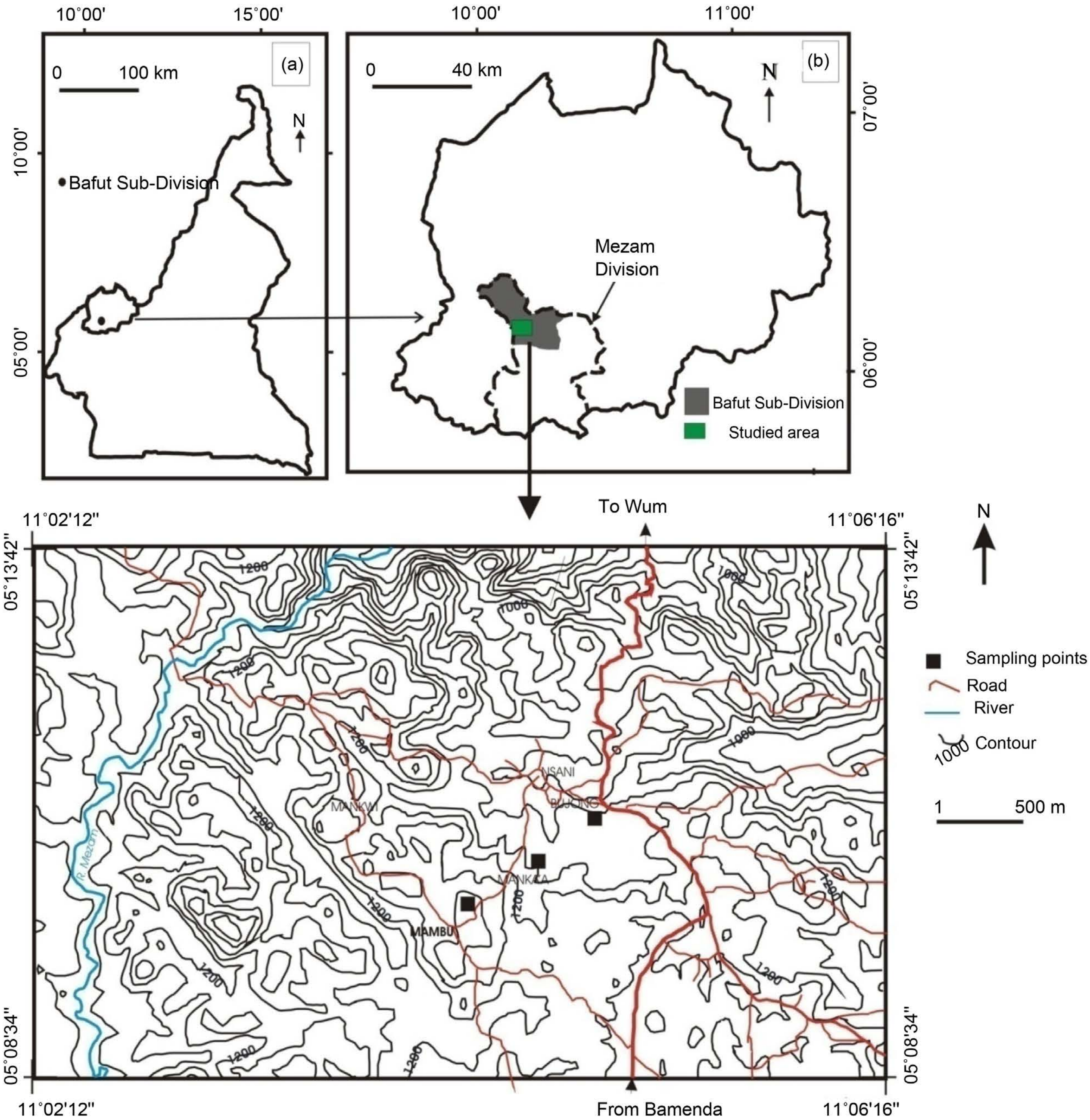


Figure 1. Relief and location of studied area. ((a): Location of Bafut-Sub-Division in Cameroon; (b): location of Bafut Sub-Division in Mezam Division).

annual temperature is 22.3˚C [25]. The natural vegetation of Bafut is the grassland savannah, marked by grasses mixed with deciduous shrubs and stunted trees here and there, meanwhile the swampy valleys are dominated by raffia bushes and palm trees [26]. This natural vegetation is strongly modified by human activities mainly farming and demographic pressure imposed by a rapidly increasing population [27]. The area is made up of undulating hills, V and U-shaped valleys. Bafut Sub-Division is drained by River Mezam (main collector) and its tributaries [28]. Geologically, Bafut Sub-Division is located within the Bamenda Mountains along the Cameroon Volcanic Line particularly along the Wum-Tungoh sector and comprises three main geological formations: volcanic rocks, metamorphic rocks and alluvial deposits [29]. The metamorphic rocks, mainly gneiss and schist, outcrop principally in the North especially on slopes of high plateaus and constitute the basement. The volcanic rocks, mostly basalts, outcrop in Southern Bafut. Granitic outcrops are also common. The alluvial deposits cover the Mezam River valley. The distribution of soils in Bafut is conditioned chiefly by topography and climate.

Thus, red ferrallitic soils occur in the southern high plateaus. In the north, most of the hill slopes are covered by brunified soils; alluvial soils are abundant in the Mezam river valley. Hydromorphic soils are common in the swampy valleys [30] [31] [32]. The estimated population of 80305 inhabitants (2005 census) is settled in three main zones: the Mumala'a (heart of the country) at the Centre clustered around the Fon's palace, the Ntare (ridge area) to the South and the Mbunti (lower) to the North which descends abruptly to the Menchum valley.

2.2. Methods

Based on several soil surveys, supported by a reconnaissance of the studied area, about twenty soil profiles representative of the area were studied through boreholes. The three most representative profiles were selected at upslope, midslope and footslope following a NE-SW transect (**Figure 2**). The characteristics of each studied topographic position are presented in **Table 1**. A randomized complete block design (RCBD) with three replications was adopted for each soil sampling position. In each sub-plot, four soil samples were randomly collected at two soil depths (0 - 20 cm and 20 - 100 cm).

Samples from each horizon were mixed together to obtain a composite sample per horizon per sub-plot. Altogether, two composite soil samples were obtained for each plot making a total number of six samples from the three topographic positions. After collection, samples were stored in clean plastic bags and conveyed to the laboratory for further processing and analysis. In the laboratory, the soil samples were air-dried at room temperature for one week and passed through a 2-mm polyethylene sieve to remove plant debris and pebbles. Afterwards, they were lightly crushed in an agate mortar to fine powder and passed through 0.149-mm nylon sieve. The physico-chemical analyses of soils were done at the "Laboratoire d'Analyses des Sols et de Chimie d'Environnement

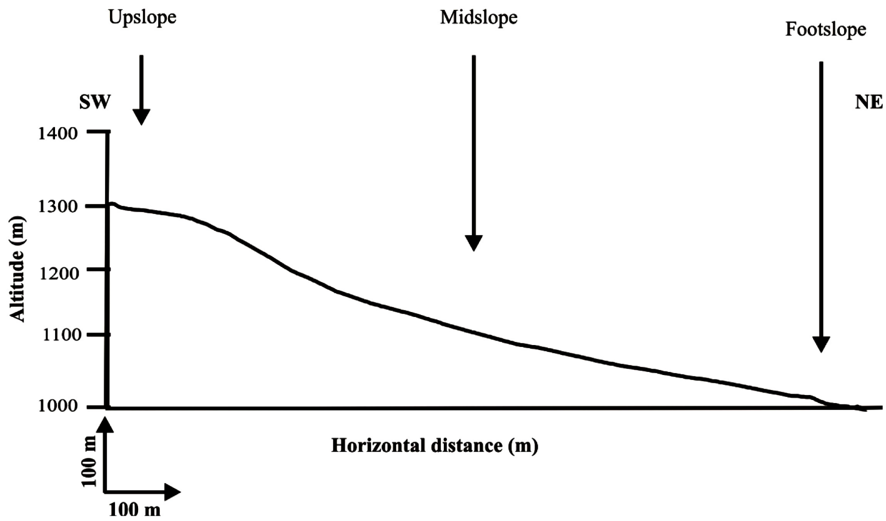


Figure 2. Topographic cross section along the studied transect.

Table 1. Studied site characteristics.

Site characteristics	Upslope	Midslope	Footslope
Altitude (m)	1300	1160	1000
Precipitation (mm)	2657.2 mm	2657.2 mm	2657.2 mm
Mean annual air temperature (˚C)	23.4	24	24.7
Mean annual soil temperature (˚C)	21	21.6	22.3
Vegetation	Grassed savannah	Grassed savannah with stunted trees	Grassed savannah with raffia
Slope gradient in % (class)	2 (Very gentle).	10 (steep)	<1 (sub-horizontal)
Parent rock	Basalt	Basalt	Basalt, colluvium
Soil type	Red ferrallitic soil	Red ferrallitic soil	Hydromorphic soil
Soil use	Farming	Farming	Farming

(LABASCE)" of the Faculty of Agronomy and Agricultural Sciences (University of Dschang, Cameroon). The soil relative humidity was determined by noting the weight-loss of an air-dried sample, after subjecting it to an oven temperature of 105˚C for 24 hours [33]. The bulk density (Db) was determined in reference to Archimedes' principle and particle density (Dp) was measured by pycnometer method [33]. Soil porosity was deduced from bulk density and particle density [33]. The particle size distribution was measured by Robinson's pipette method [33]. The pH-H_2O was determined in a soil/water ratio of 1:2.5 and the pH KCl was determined in a soil/KCl composition of 1:2.5 [34]. The organic carbon (OC) was measured by Walkley-Black method [35]. The organic matter (OM) content was obtained from organic carbon (OC) using the Sprengel factor (OM = OC × 1.724) [35]. Total nitrogen (TN) was measured by the Kjeldahl method

[36]. Available phosphorus was determined by concentrated nitric acid reduction method [37]. Exchangeable cations were analyzed by ammonium acetate extraction at pH 7 [38]. The cation exchange capacity was measured by sodium saturation method [39]. The base saturation corresponds to the ratio of the sum of exchangeable cations (S) and cations exchange capacity (CEC). The exchangeable aluminum was extracted in a 1M KCl solution and evaluated by colorimetry with the violet pyrocathecol method (VPC) according to [40]. Aluminum toxicity was defined by the Kamprath method [41]:

$$m = \frac{Al}{Al + S} \times 100$$

The structural stability index (*SI*) was obtained using the following equation [42]:

$$SI = \frac{1.724OC}{(\text{silt} + \text{clay})} \times 100;\ 0 \le SI \le \infty$$

The slaking index (*Is*) was estimated from the following formula for acid soils [43]:

$$Is = \frac{1.5Lf + 0.75Lg}{C + 10OM} - 0.2(pH - 7)$$

where Lf is % fine silt, Lg is % coarse silt, Cl is % clay and OM is % organic matter.

Version 4 (**Table 2**) of the FCC [22] [44] was used to identify soil fertility limitations and to classify soils into FCC units. This system consists of two categorical levels of classification. The first (type/substrata type), describes topsoil and subsoil texture and is expressed in capital letters. The second (condition modifier) consists of 17 modifiers defined to delimit specific soil conditions affecting plant growth with quantitative limits. Each condition modifier is represented as a lower case letter, while + or - indicate greater or lesser expression of the modifier. Main soil fertility limitations for crop cultivation included heavy clayey texture (C), waterlogging (g), organic matter depletion (m) and vertic properties (v).

The land and climatic parameters limiting the growth and production of major crops in the area (huckleberry, maize, beans and groundnut) were evaluated by simple limitation and parametric methods of [45] [46]. The fertilizer requirements for the correction of nutritional deficiencies were calculated as the amount of Ca, Mg and K in the ideal situation of equilibrium (76/18/6) minus that in the actual soil [47].

3. Results and Discussions

3.1. Soil Morphology

The soil morphological characteristics are summarized in **Table 2**. The upslope and midslope soils showed a surface dark brown colour and a subsurface dark

Table 2. (a) Morphological characteristics of the surface soils; (b) Key of soil characteristics.

(a)

Soil characteristics		Upslope		Midslope		footslope	
		Ap (0 - 20 cm)	A_1 (20 - 100 cm)	Ap (0 - 20 cm)	A_1 (20 - 100 cm)	Ap (0 - 20 cm)	A_1 (20 - 100 cm)
Colour (moist)	Code	7.5YR3/3	10R3/6	5YR3/4	10R3/6	7.5YR4/1	7.5YR4/1
	Color	Dark brown	Dark yellowish brown	Dark brown	Dark yellowish brown	Dark grey	Dark grey
Structure		Vf, l & m	m	Vf, l & m	m	f, m & s	m
Consistency	Dry	s	h	s	h	s	h
	Wet	s & p	s & p	s & p	s & p	s & p	s & p
Rock fragments		n	n	n	n	n	n
Roots		c, f	f, f	c, f	f, f	c, f	f, f

(b)

Structure			Consistency		Rock fragments	Roots	
Size	Type	Grade	Dry	wet		Abundance	Thickness
vf = very fine (<5 mm) f = fine (5 - 10 mm) m = medium (10 - 20 mm) c = coarse (20 - 50 mm) vc = very coarse (>50 mm) 1 = weak; 2 = moderate; 3 = strong;	g = granular ab = angular blocky sb = subangular blocky l = lumpy m = massive	w = weak (peds barely observable) m = moderate (peds observable) s = strong (peds clearly observable)	l = loose s = soft h = hard	s = sticky p = plastic	n = none (0%) v = very few (0% - 2%) c = common (5% - 15%) m = many (15% - 40%) a = abundant (40% - 80%) d = dominant (>80%)	f = few; c = common	f = fine; m = medium

yellowish brown colour, while the downslope soils were dark grey at surface and subsurface. The structure was very fine, lumpy and massive at the surface to massive at depth. The surface horizons were soft and friable when dry but soft and plastic under wet conditions; meanwhile the subsurface horizons were hard when dry but soft and plastic when wet. Rock fragments were absent while plant roots were fine and common in the bottom horizons but fine and few at subsurface. Similar soils have already been described in the Bambouto Mountains of Western Cameroon and were classified as andic ferrallitic soils [3] [17] [18].

3.2. Soil Physico-Chemical Properties

The studied soil physico-chemical characteristics are presented in Table 3. The soils showed a high (1.5 - 1.8 g·cm^{-3}) bulk density and low porosity (30.76% - 42.3%); nevertheless, the porosity was slightly lower for the footslope soils. This could be due to lateral migration and accumulation of fine earth material at the lower positions leading to an increase in bulk density of the soils. The soil texture

Table 3. Soil physico-chemical characteristics along the soil catena in Bafut.

Soil Characteristics	Upslope		Midslope		Footslope	
	Ap (0 - 20 cm)	A_1 20 - 100 cm)	Ap (0 - 20 cm)	A_1 (20 - 100 cm)	Ap (0 - 20 cm)	A_1 (20 - 100 cm)
Moisture content (105˚C)	16.3	18.42	8.20	16.21	15.80	15.21
Particle density ($g{\cdot}cm^{-3}$)	2.6	2.6	2.6	2.6	2.6	2.6
Bulk density ($g{\cdot}cm^{-3}$)	1.7	1.8	1.5	1.7	1.7	1.7
Porosity (%)	34.6	30.76	42.3	34.6	34.6	34.6
Texture	55	48	23	32	26	31
	10	12	34	17	20	21
	35	40	43	51	54	48
	Sandy clay	Sandy clay	Clay	Clay	Heavy clay	Clay
pH (H_2O)	4.3	5.3	4.4	5.2	4.6	5.8
pH (KCl)	4.0	4.9	4.3	4.9	4.4	5.4
ΔpH	0.3	0.4	0.1	0.3	0.2	0.4
Organic carbon (% dry matter)	4.8	0.79	3.7	0.46	5.1	1.86
Organic matter (%)	8.3	1.36	6.36	0.79	8.9	3.21
Total nitrogen (% dry matter)	0.42	0.03	0.08	0.04	0.56	0.12
Exchangeable cations (cmol + kg^{-1})	1.6	1.99	1.9	1.43	3.6	2.11
	1.40	0.87	1.12	1.02	1.5	0.39
	0.2	0.13	0.16	0.25	0.29	0.54
	0.08	0.06	-	0.01	0.10	0.06
Sum of exchangeable bases (cmol + kg^{-1})	5.19	3.02	3.18	2.71	5.49	3.1
CEC at pH7 (cmol + kg^{-1})	20.9	8.6	16.05	8.11	25.6	12.08
Apparent CEC (CECapp) (cmol + kg^{-1})	13.14	14.7	8.79	12.80	14.44	11.79
Available phosphorus (ppm)	30.9	7.01	22.1	5.11	27.06	3.97
Exchangeable Al (cmol + kg^{-1})	1.85	0.79	0.56	0.26	1.59	0.21
Al toxicity (%)	26.27	20.73	14.97	8.75	22.45	6.34

ranged from sandy clayey at the upslope to clayey at the midslope and heavy clayey at the footslope. The gravel content was low, due probably to the volcanic nature of the parent material which undergoes intense weathering under humid tropical climate favourable to leaching and the uneven and aggressive nature of the relief that promote excellent drainage and erosion [20] [48] [49] [50]. The studied soils revealed a uniform particle density of 2.6 $g{\cdot}cm^{-3}$. Organic matter contents were very high in all the soils and decreased with increasing slope and depth, and lowest values were recorded at mid-slope. These results match the findings of [51]. Low mean temperature and high annual rainfall might be inducing high plant biomass production and decreasing SOC decomposition rates, both leading to SOC accumulation [52] [53]. The pH values were globally less than 5 revealing very acidic soils [50]. In such soils Al and Mn are often toxic, Ca, Mg and Mb might be deficient [44]. The exchangeable cations were as follows: Ca was low to very low, Mg was low, K was low to very low and Na was very low. The sum of exchangeable bases was low at the upslope and midslope but moderate higher at the footslope. This might imply leaching from the upper landscape positions and deposition at the footslope [48] [50]. Leaching of bases under high rainfall conditions typical of tropical ecosystems, might be the primary cause of acidic soil reactions [51]. The CEC was low for all the soils of the different positions. The available phosphorus was also moderate for all the soils. The Al toxicity of all the soils was moderate; values were higher at the upslope and gradually decreased downslope (**Table 3**). Also, Al toxicity was higher for the surface horizons than for the bottom ones. The availability of Phosphorus is often low in the presence of free Al and Fe through binding of P, Al and Fe [46] carbon content in mountainous ecosystem might be related to an earlier release of amorphous compounds such as allophane and ferrihydrite which have a strong stabilizing effect on organic compounds [19] [20] [54]. Soil clay content has a strong influence on soil's ability to store and amass soil OC as the latter is stabilized through the formation of clay-humic complex [55].

3.3. Soil Nutrient Ratios and Fertility Indices

The soil nutrient ratios and fertility indices (**Table 4**) enabled to assess the actual fertility level of the studied soils without any addition of fertilizers. The silt/clay ratios of the upslope and footslope positions ranged from 0.28 to 0.79, the higher values attributed to the midslope surface horizon. The silt/clay ratios of the upslope and footslope positions were low (<0.75) indicating old age pedogenenetic processes, while the midslope had a moderate ratio (>0.75) indicating moderate age pedogenetic surface according to [49]. The relatively younger age of the midslope material is consistent with a steep slope that favours erosion and continuous rejuvenation of the soil prior to their formation [50]. The C/N ratios were low to very high, ranging from 9.11 to 55.71. These values were highest for the upslope and midslope, but low to moderate for the footslope. The TN/pH ratio (‰ total nitrogen-to-pHH_2O ratio) was very low for upslope and midslope and high for the footslope soils. The base saturation (S/T ratio) globally ranged from 22.62% to 32.55%, with lowest values at the midslope (**Table 4**). The N/P ratios (or nitrogen mineralization indices) were lowest for upslope, moderate for midslope and highest for the footslope soils (**Table 4**). The high values revealed potential risk of nitrogen deficiency and vice versa (Prusty *et al.* 2009). In such soils, low nitrogen levels could be hindering available phosphorus uptake due to ionic imbalance equilibrium [56]. The C/P ratios (or phosphorus mineralization indices) ranged between 1992 and 3289 (**Table 3**). These values, higher than 200, probably indicate a slow turn-over rate for soil available phosphorus [55]. The Ca/Mg ratios ranged from 1.1 to 2.6, with highest values at the footslope and

Table 4. Nutrient fertility ratios and indices.

Fertility parameter	Upslope		Midslope		Footslope	
	Ap (0 - 20 cm)	A1 20 - 100 cm)	Ap (0 - 20 cm)	A1 (20 - 100 cm)	Ap (0 - 20 cm)	A1 (20 - 100 cm)
SSI	18.44	2.62	8.26	1.16	12.03	4.65
Slaking index	0.21	0.23	0.55	0.43	0.64	0.48
Silt/clay ratio	0.28	0.30	0.79	0.33	0.37	0.44
C/N ratio	11.42	26.33	46.25	11.50	9.11	15.5
TN/pH ratio	0.01	0.01	0.02	0.01	0.12	0.02
N/P ratio	13.59	0.43	3.62	0.78	20.69	30.23
C/P ratio	1553.39	1114.25	1674.21	900.20	1884.7	4687.14
Ca/Mg ratio	1.14	2.29	1.70	1.40	2.40	5.41
Mg/K ratio	7	6.69	7	4.08	5.17	0.72
ESP (%)	0.72	0.29	-	0.12	0.39	0.49
S/CEC pH7 (%)	24 .83	36.97	19.27	27.07	21.44	25.66
Ca/Mg/K ratio	50/43.75/6.25	66.6/29.01/4.34	59.74/35.22/5.03	52.96/37.78/9.26	66.75/27.83/5.38	69.40/12.82/17.78
CRC	0.66/2.43*/1.04	0.86/1.62*/0.72	0.79/1.95*/0.84	0.69/2.09*/1.54*	8.88/1.56*/0.89	0.91/0.71/2.96*
F	0.18	0.19	0.17	0.21	0.46	0.34
CECapp/Clay ratio	0.36	0.37	0.79	0.25	0.26	0.25

CRC: coefficient of relative concentration; ESP: Exchangeable sodium percentage; F: Forestier's index (S2/(Clay + fine silt)); SSI: Structural stability index.

lowest ones at upslope. Apart from the footslope positions, all the other landscape positions showed a Ca/Mg ratio of less than 2 suggesting a cationic imbalance between Mg and Ca [57] [58]. The Mg/K ratio ranged from 3.4 to 10.9. The highest Mg/K ratios appeared at the upslope while the lowest ones were observed at the footslope. The Mg/K ratios ranging between 3.4 and 10.9 in all the positions suggest normal to optimum levels of Mg and K in the soils, suitable for plant uptake [57]. The Ca/Mg/K equilibrium revealed that Mg was the most concentrated element amongst the three basic cations as shown by its highest coefficients of relative concentration (1.4 to 2.4) (**Table 3**). The Ca/Mg/K ratio revealed a cationic imbalance relative to the ideal equilibrium values of 76% Ca, 18% Mg and 6% K of [59] adequate for maximum plant nutrient uptake (**Figure 3**). The exchangeable sodium percentage (ESP) was very low for all the landscapes, although slightly higher for the upslope soils (up to 6%). The Forestier's fertility indices of [60] were extremely low (<1) for all topographic positions (**Table 4**). This agrees with low base contents according to [61]. The CEcapp/clay ratios varied between 0.28 and 0.34, but were slightly higher at footslope than the other positions (**Table 4**). Such low ratios are typical of kaolinitic soils [33]. The structural stability indices ranged from 7.9 to 15.1. The highest indices were noted at upslope position and the lowest ones at midslope. The structural stability indices were all greater than 9, indicating a stable structure to degradation [42]. The slaking indices were very low and ranged from 0.21 to

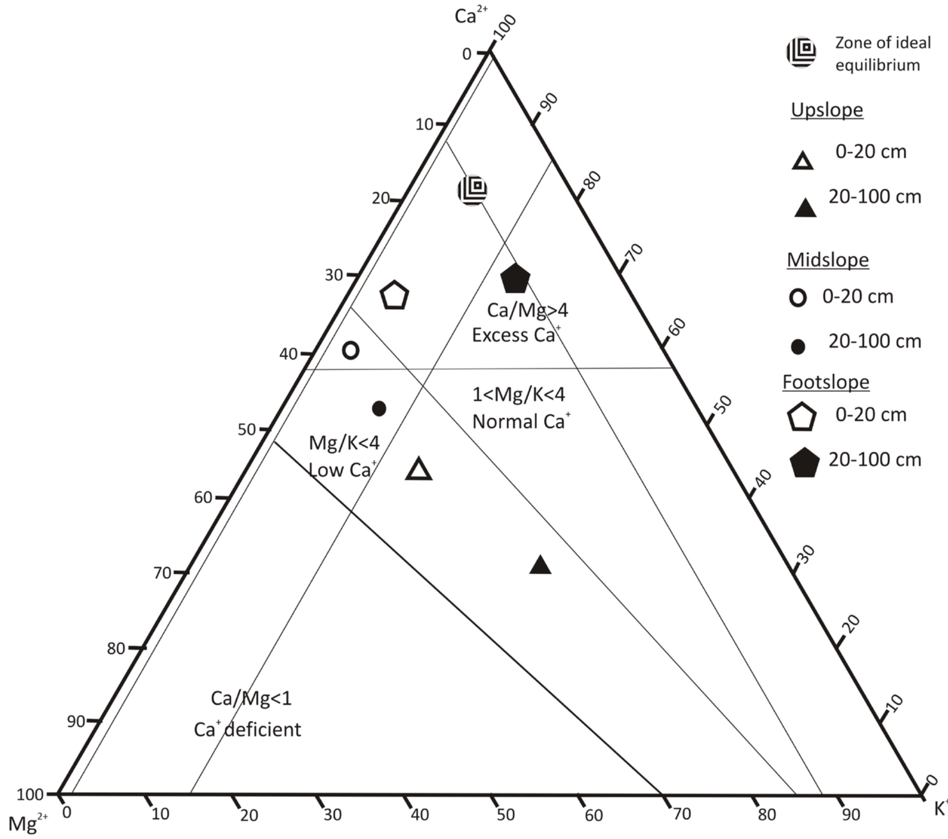


Figure 3. Ca/Mg/K equilibrium diagram in reference to [59].

0.68 (**Table 4**). These values are within the range of non-slaking soils [43]. It is realized that the surface horizons showed very high slaking index values and this is related to their high organic matter contents. Soil organic matter (OM) is an essential component of soil quality, governing processes like carbon sequestration, nutrient cycling, water retention and soil aggregate stability [62]. Low soil OM reduces soil aggregate stability and increases the risk of soil to high erosion rates and soils with high OM retain more water [63]. The sub-surface horizons with low organic matter contents show low structural stability values. The Bafut soils fell within the low to medium fertility range [22] [64] [65].

3.4. Soil Fertility Limitations and Fertility Capability Classification (FCC)

The major constraints of the upslope soils to crop production were aluminum toxicity, high leaching potential, low nutrient capital reserve (**Table 5**). For midslope soils, constraints were massive clay, aluminum toxicity, high leaching potential and low nutrient capital reserve. As for the footslope soils, massive clay, Al toxicity, high leaching potential, waterlogging, low nutrient capital reserve and organic matter depletion were the major constraints. The studied soils were thus classified in the FCC system as aek for the upslope soils, Caek for the midslope soils and as Cagk for the footslope soils (**Table 5**).

Table 5. Soil fertility limitations and fertility capability classification (FCC) units in reference to [64].

Categorical levels		Upslope	Midslope	Footslope
Type		–	C	C
Substrata type		–	–	–
Modifiers	a	+	+	+
	b	–	–	-
	e	+	+	-
	g	–	–	+
	k	+	+	+
	m	+	+	+
FCC		aek	Caek	Cagk

C: clay; a: aluminium toxicity; b: basic reaction; e: high leaching potential; g: waterlogging; k: low nutrient capital reserve; m: organic matter depletion; v: vertic properties; +: greater expression of the modifier; –: lesser expression of the modifier.

3.5. Suitability of Soils for Crop Production

The fertility status of these soils was studied through land evaluation using simple limitation and parametric methods [52]. This process enables to identify potential soil fertility constraints to the production of agricultural crops, and thus provides valuable information in designing appropriate soil management strategies for the sustainable crop production [66]. The studied soils are widely used for cultivation of maize, huckleberry, groundnut and beans. Precipitation and mean temperature during crop cycle, the studied soils were suitable for cultivation of huckleberry, beans, maize and groundnut, but precipitation was very suitable for beans (**Table 6**). Annual precipitation was potentially not suitable for groundnut and huckleberry but marginally suitable for maize and beans at upslope and midslope. At footslope, annual precipitation was potentially not suitable for huckleberry and maize but marginally suitable for groundnut and beans. Based on slope, upslope and downslope soils were very suitable for all these crops but midslope soils were suitable for huckleberry and maize, but moderately suitable for groundnut and beans. Based on wetness, the studied soils were very suitable for all the crops, except footslope soils where they were potentially unsuitable for all the crops. The soil physical properties revealed that coarse fragments contents and soil depth were very suitable for all the crops in all the topographic positions (**Table 6**). Based on texture/structure, the midslope and footslope soils were very potentially not suitable for beans and maize, but midslope soils were suitable for groundnut and huckleberry performance. Finally, texture/structure of footslope soils was suitable for huckleberry and moderately suitable for groundnut. Based on sum of exchangeable bases, the upslope and footslope soils were very suitable for all the crops meanwhile the midslope soils were moderately suitable. All the studied topographic positions showed moderate limitation and moderately suitability with respect to base saturation and apparent CEC for all four crops, except for groundnut with slight limitation based on apparent CEC. The crops showed no limitation with respect to organic carbon content and salinity. However, all the studied crops showed very severe limitation (N_2) with respect to pH(H_2O), with potentially unacceptable

Table 6. Suitability of the studied soils for the production of maize, beans, groundnuts and huckleberry.

Landscape, soil and climatic characteristic	Upslope				Midslope				footslope			
	Groundnut	huckleberry	Maize	beans	Groundnut	huckleberry	Maize	beans	Groundnut	huckleberry	Maize	beans
Climate (c)												
Precipitation during crop cycle (mm)	S1-1	S1-1	S1-1	S1-0	S1-1	S1-1	S1-1	S1-0	S1-1	S1-1	S1-1	S1-1
Mean T˚C during crop cycle (˚C)	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1
Annual Precipitation (mm)	N2	N2	S3	S3	N2	N2	S3	S3	S3	N2	N2	S3
Topography (t)												
slope	S1-0	S1-0	S1-0	S1-0	S2	S1-1	S1-1	S2	S1-0	S1-0	S1-0	S1-0
Wetness (w)												
Flooding	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	N2	N2	N2	N2
drainage	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	N2	N2	N2	N2
Soil physical characteristics (s)												
Texture/structure	S1-1	S1-1	S1-1	S1-1	S1-0	S1-1	N2	N2	S2	S1-1	N2	N2
Course fragments (%)	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0
Soil depth (cm)	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0
Soil fertility (f)												
S (cmol + kg^{-1})	S1-0	S1-0	S1-0	S1-0	S2	S2	S2	S2	S1-0	S1-0	S1-0	S1-0
CECapp (cmol + kg^{-1})	S1-1	S2	S2	S2	S1-1	S2	S2	S2	S1-1	S2	S2	S2
Base saturation (%)	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2
pH (H_2O)	N2	N2	N2	N2	N2	N2	N2	N2	N2	N2	N2	N2
OC (%)	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0
Salinity (n)												
ESP (%)	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0
Suitability												
Class	S2fN2cf	S2fN2cf	S2fS3cN2f	S2fN2f	S2fN2cf	S2fN2cf	S2fN2csf	S2ftS3cN2sf	S2sfS3cN2wf	S2fS3cN2cwf	S2fNwsf	S2fS3cN2wf

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%); 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%).

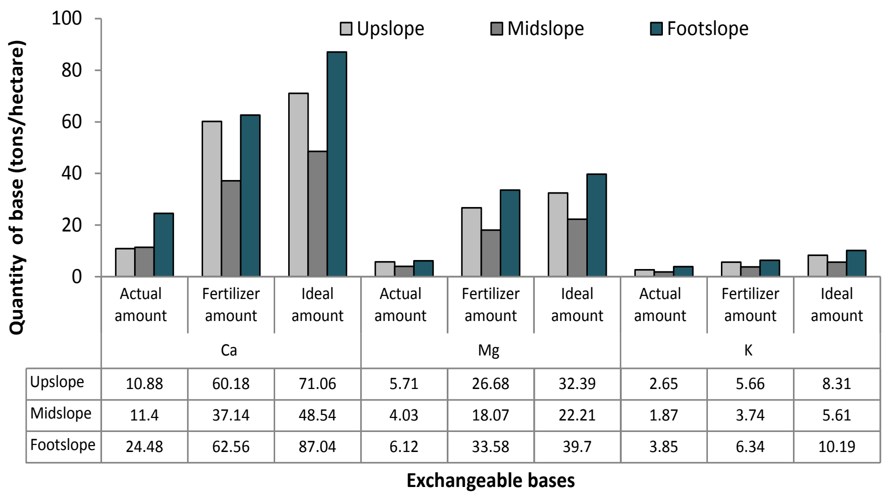
yields (0% - 25%). These results are consistent with those already documented by [4] in the Bambouto Mountains of Western Cameroon.

3.6. Quantification of Nutritional Deficiencies

Quantification of nutritional deficiencies in soils requires raising the base saturation to 50% (adequate for the growth of most plants according to [46]) by adding the basic cations in a controlled matter. **Figure 4** reveals that for fertilizer requirements of Ca, the highest amounts were observed for the footslope soils (62.56 tons/ha) followed by the upslope (60 tons/ha) and the lowest for the midslope soils (37.14 tons/ha). Mg fertilizer requirements ranged from 18.07 tons/ha (midslope) to 33.58 tons/ha (upslope). The K fertilizers needs were far below those of Ca and Mg, ranging between 3.74 tons/ha (midslope) to 6.34 tons/ha (footslope). The lowest requirements of all the three elements for the three topographic position soils might be related to the low bulk density (1.5 g·cm^{-3} compared to 1.7 for the others topographic positions) of the midslope soil at 0 - 20 m depth which tremendously reduces the mass of soil per unit volume [47].

4. Conclusion

The objective of this work was to study the major characteristics of some mountainous soils in the North-western Highlands of Cameroon and to evaluate their potentials for the production of some common tropical crops. The principal results revealed that those soils are dark-coloured with a sandy clayey to clayey texture, a very high compacity and a very acidic reaction. The organic matter, total nitrogen, available phosphorus and C/N ratio were mainly high at the surface. All the exchangeable bases were low in relation to leaching processes that dominate mountainous landscapes. Leaching of bases under high rainfall conditions might be responsible for the acidic reaction of those soils. The sum of exchangeable bases (S), cation exchange capacity (CEC) and base saturation were



	Ca Actual amount	Ca Fertilizer amount	Ca Ideal amount	Mg Actual amount	Mg Fertilizer amount	Mg Ideal amount	K Actual amount	K Fertilizer amount	K Ideal amount
Upslope	10.88	60.18	71.06	5.71	26.68	32.39	2.65	5.66	8.31
Midslope	11.4	37.14	48.54	4.03	18.07	22.21	1.87	3.74	5.61
Footslope	24.48	62.56	87.04	6.12	33.58	39.7	3.85	6.34	10.19

Figure 4. Quantification of exchangeable bases deficiencies and correction.

low at the upslope and midslope but modest at the footslope position. The Ca/Mg/K ratio was imbalance relative to the ideal equilibrium condition of 76/18/6 and Mg was the most relatively concentrated exchangeable base. There was a clear variation of most of the soil properties along the slope and with depth. The soils were classified in the FCC system as aek for the upslope soils, Caek for the midslope soils and Cagkm for the footslope soils in FCC system. The principal limitations to the production of huckleberry, bean, maize and potatoes in Bafut were heavy rainfall, wetness, steep slope, soil texture/structure and soil fertility decline. These constraints might be overcome by cultivation of such crops at the end of the raining season, contour ploughing, terracing, fertilization and liming.

Conflict of Interests

The authors declare no conflict of interests.

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