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Research Article

Morphology, Physico-Chemical Characteristics, Nutrient Status and Fertility Capability Classification of Andosols under Different Land Use Systems in Foumbot (Cameroon Western Highlands)

Genesis Kunghe[1]*, Primus Azinwi Tamfuh[1,2], Lionelle Estelle Mamdem[3], Georges Martial Ndzana[1], Désiré Evariste Moundjeu[1], Cedric Nguemezi[4], Paul Tematio[4] and Dieudonné Bitom[1]

[1]*Department of Soil Science, Faculty of Agronomy and Agricultural Sciences, University of Dschang, P. O. Box 222, Dschang, Cameroon*

[2]*Department of Mining and Mineral Engineering, National Higher Polytechnic Institute, University of Bamenda, P. O. Box 39 Bambili, Cameroon*

[3]*Department of Earth Sciences, Faculty of Science, University of Yaoundé I, P.O. Box 812, Yaoundé, Cameroon*

[4]*Department of Earth Sciences, Faculty of Sciences, University of Dschang, P.O. Box 67, Dschang, Cameroon*

Abstract

Demographic explosion in developing countries over the past years has increased the demand for food, leading to intense pressure on soils and land fertility decline. This work aims to determine the effects of different land use systems on soil physico-chemical properties, nutrient status and fertility classification in order to understand the causes of soil fertility and crop productivity decrease in the study area, in the Noun agricultural basin (Cameroon Western Highlands) for more sustainable management. Thus, five land use systems (three replicates each): primary forest (P0), tillage (>10 years=T), burnt land (>10 years =B), Fertilized farm (>10 years = FF) and fallow (>10 years = F). Composite soil samples were randomly collected from each land use system and analyzed in the laboratory using standard methods. The main results showed that, compared to the primary forest, tillage reduced soil pH from 5.70 to 5.10, soil organic matter (SOM) from 12.0% to 9.23%, Total Nitrogen (TN) from 0.30% to 0.10% and cation exchange capacity (CEC) from 37.0 to 20.0 cmol•kg–1, but increased bulk density. Burning reduced SOM (12.0% to 9.16%), TN (0.30% to 0.26%) and CEC (37.0 to 31.0 cmol•kg–1) but increases soil pH (5.70 to 5.73) and Sum of Exchangeable Bases (SEB). Fertilizer applications reduced soil pH, SOM, but increased TN, Available Phosphorus (AP) and SEB. In comparison with tillage, fallow showed higher SOM, TN, AP, CEC and structural stability. Generally, tillage, burning and fertilization deteriorated the soils, whereas fallowing restored them. Soil fertility capability classification reveals three fertility classes: very good soils (fallow and primary forest), good soils (fertilized land) and average soils (tillage and burned soils). The studied soils are very suitable for the cultivation of maize and green beans with low pH limitations in tillage. Best management practices ought to be minimum tillage, fallow, use of organic manure and integrated fertilization.

Keywords: Andosols; Cameroon Western Highlands; Land use systems; Soil capability classification; Soil fertility; Soil nutrients

***Corresponding author:** Genesis Kunghe, Department of Soil Science, Faculty of Agronomy and Agricultural Sciences, University of Dschang, P. O. Box 222, Dschang, Cameroon; Email: kunghegenesis95@gmail.com

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Introduction

Soils are affected by physical, chemical and biological processes at or near the earth surface [1]. Land use system has been defined as the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it [2-3]. Land use system information can be used to develop solutions for natural resource management issues such as soil fertility management and water quality. Deforestation [4], urban development, agriculture, and other human activities have substantially altered the earth's natural resources [5-7]. Such disturbances on the land, affect the important ecosystem processes and services, which can have wide-ranging and long-term consequences. Land use system change may induce changes in the biological, physical, chemical, and hydrological properties of soils. Conversion of terrestrial ecosystems such as forest and natural savannah for cultivation, grazing, and settlement generally results in a decrease in soil organic matter. Tellen and Yerima stated that soils could differ in physical properties based on land use system types. These physical properties are crucial to root growth, infiltration, water and nutrient holding capacity. Agriculture plays an important role in the economy of many African countries. In Cameroon, agriculture contributes to about 45% of the Gross Domestic Product (GDP) and 65% of full-time employment [8-12]. The study area has witnessed a rapid increase in population over the years (from 67.000 inhabitants in 2005 to 90.000 inhabitants in 2022) leading to increase in food demand, and intense soil cultivation. The soil is submitted to intensive agricultural activities for annual and seasonal food crop production, using most inappropriate land use systems [13]. As a result, yields are relatively low and land productivity is consequently decreasing [14]. The Foumbot community is highly dependent on agriculture for livelihood, thus necessitating soil evaluation under some selected land use systems in this agro-ecological basin and to suggest agricultural management practices to improve on agricultural yields. Many

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studies have addressed the effects of land use system changes on soil properties in Western Cameron. The works of [6] omitted the effects of fertilizers on soil properties. Similarly, limited their work to the effects of land use system on soil properties. Very little work has been done to evaluate the effects of land use systems on soil Physico-chemical properties, nutrient status and fertility capability classification in the studied area. Considering the conditions of the Andosols of the Noun Valley, characterized by rapid degradation of most of their Physico-chemical properties because of method of cultivation, new strategies for sustainable management of the soils need to be found. Thus, it might be useful to identify the land use systems effects on soil Physico-chemical properties, nutrient status and soil fertility classification in Foumbot (Cameroon Western Highlands). The main objective of the present study was to determine the effects of different land use systems on soil Physico-chemical properties, nutrient status and to perform a fertility classification in order to understand the causes of soil fertility and crop productivity decrease in the study area. The results obtained will serve as important data to local farmers and the Cameroonian government on soil fertility management.

Materials and Methods

Description of the study area

The study was carried out in Foumbot, located in the Noun Division, of the West region of Cameroon. It is situated at approximately 27 km north of Bafoussam town between latitude 05^0 25' to 05^0 42' N and longitude 10^0 34' to 10^0 43' E (Figure 1). It covers an area of 579 Km2, spreading over the Noun valley situated within the Bamileke and the Bamoun plateaus. It is subjected to a mountainous tropical climate, of Cameroon type and characterized by two main seasons: a long rainy season (mid-March to mid-November) and a short dry season (between mid-November and mid-March). Mean annual rainfall is about 1900 mm and the mean annual temperature is 21°C. The study area is an undulating plain with a main altitude of about 1130 m, embedded on a Precambrian basement made of metamorphic rocks (gneiss and migmatites), with many granitic intrusions and partly covered by a thick layer of volcanic deposits [15-17]. According to [15], soils of the study area include Andosols, Acrisols, Ferrasols and Gleysols in some valleys. The area is drained mainly by small streams in addition to the Nkoup River, which longitudinally crosses a major part of the study area. The total population of Foumbot is estimated at 90.406 inhabitants. More than half of the people live in a rural area where farming is the main activity. The main activity of population in the area is subsistence agriculture. Dominant crops of the area are maize, tomato, beans soybeans and Irish Potato [18-19]. Its vegetation, which was originally made of natural dense forest, has been altered because of anthropogenic activities.

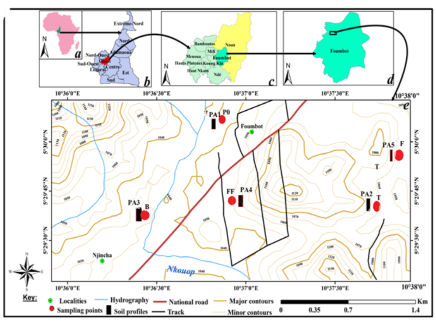

Figure 1: Map of Cameroon (b) showing the position of Foumbot in the West Region (c), Noun Division (d) and the studied area (e)

Methodology

Experimental design

The studied land use systems were: primary forest (P0), tillage (>10 years=T), burnt land (> 10 years =B), Fertilized farm (>10 years long-term = FF) and fallow (>10 years =F). Three plots were selected per land use system. All land use systems were on Andosols with an undulating topography. The characteristics of each of the sites are compiled in Table 1.

Morphological characterization and sample collection

The study was carried out on Andosols. Five representative soil profiles were dug on the selected land use systems of the study area. The profiles include: profile on primary forest (PA1), profile on tillage (PA2), profile on Burnt land (PA3), profile on fertilized farm (PA4) and profile on fallow (PA5), (Table 1). The soil profiles were described according to [20]. On each profile, samples were collected at different horizons for physicochemical analysis in the laboratory. Soils descriptions and soil classification was based on [21].

Site characteristics	Primary forest	Tillage	Burned land	Fertilized farm	Fallow
Latitude	05° 30' 36" N	05° 29' 67" N	05° 29' 64" N	05° 29' 47" N	05° 29' 38" N
Longitude	10° 37' 00" E	10° 38' 29" E	10° 38' 19" E	10° 37' 7" E	10° 39' 11" E
Altitude	1052 m	1067 m	1074 m	1058 m	1049 m
Slope class	Flat slope	Gentle slope	Gentle slope	Flat slope	Gentle slope
Mean annual precipitation (mm)	1900	1900	1900	1900	1900
Mean annual temperature (0C)	21.2	21	21	21.3	2.3
Parent rock	Pyroclastic materials	Pyroclastic materials	Pyroclastic materials	Pyroclastic materials	Pyroclastic materials
Soil type	Andosols	Andosols	Andosols	Andosols	Andosols
Vegetation	Dense forest with trees	Maize farm	Herbaceous plants	Tomatoes	Trees and savanna
State of erosion	Mild	high	High	moderate	mild

Table 1: Site characteristics of the study land use systems.

P0: primary reference forest, T: tillage land use system, B: burned land use system, FF: fertilized land use system, F: fallow land use system.

Four representative sites were selected, based on their land use system practice. The sites are: Tillage (T), Burnt Farm (B), Fertilized Farm (FF) and Fallow (F). In each land use system, three composite surface soil samples were randomly collected at 0-30 cm depth using a soil auger and trowel. Three composite soil samples were also collected in the primary forest (P0: reference). Undisturbed core samples were collected with a 100 cm^3 Kopecky ring for bulk density determination. A total of 13 composite soil samples were collected in all the selected land use systems. The auger and trowel were washed with distilled water after collection of each sample before using it at the next sampling site to avoid cross contamination. The reference site has the same geology and soil type as the representative or experimental sites. For each soil sample (about 1 kg), litter and gravel were removed, and the sample was stored in a clean polyethylene bag and labeled. The soil samples were taken to the laboratory for further description and analysis.

Laboratory analyses of soils

The physico-chemical analyses were carried out at the Research Unit of Soil Analysis and Environmental Chemistry of the University of Dschang (Cameroon). Disturbed soil samples from the field were air-dried in the laboratory, crushed in a mortar using a pestle and sieved through a 2 mm sieve to obtain fine soil fractions(particle size<2 mm). The fine earth was then analysed for the various physico-chemical properties using standard methods [22]. For physical properties, Bulk Density (BD) was determined by pycnometer method, particle density was obtained in reference to Archimedes' principle and particle size distribution was determined by Robinson pipette method [23]. For chemical analyses, pH- H_2O and pH-KCl were determined in a soil-to-water ratio of 1:2.5 and a soil-to-1 N KCl solution of 1:2.5, respectively. The Soil Organic Carbon (SOC) was determined by the Walkley and Black method [24]. The Total Nitrogen (NT) was determined by the Kjeldahl method. Available phosphorus (P) was determined by Bray II methods [25]. For the determination of CEC and exchangeable bases, the soil sample is leached with ammonium acetate at pH 7. The exchangeable bases (Ca^{2+}, K^+ and Na^+) are determined by Atomic Absorption Spectrometry. CEC is determined immediately after the exchangeable bases using the same sample and tube. The structural Stability Index (SI) was estimated according to equation (1) [26].

$$SSI = \frac{1.724 * \%\,OC}{\%\,silt + \%\,clay} * 100\ ;\ 0 \leq SSI \leq \infty \qquad (1)$$

Where OC is the organic carbon content in the soil. SSI > 9% stable soils; 7% < SSI ≤ 9% low risk of degradation; 5% < ISS≤7% high degradation.

The Forestier index indicates the reserve in exchangeable bases of a soil [27].

$$FI = \frac{S^2}{Clay + Silt} \qquad (2)$$

When this index is above 1.5, good bases reserve and when FI < 1.5 is low bases reserves.

The Fertility Limitations and Capability Classification (FCC) of the studied soils was in accordance with the works of [29, 60, 65, 66] as shown in Table 2.

Characteristics	Level I (no limitation)	Level II (moderate limitation)	Level III (severe limitation)	Level IV (very severe limitation)
OM (%)	>2	1-2	0.5-1	<0.5
N (%)	>0.08	0.045-0.08	0.03-0.045	<0.03
P(mg/kg)	>20	10-20	5-10	<5
K(cmol.kg-1 soil)	>0.4	0.2-0.4	0.1-0.2	<0. 1
TEB(cmol. kg-1 soil)	>10	5-10	2-5	<2
S/CEC (%)	>60	40-60	15-40	<15
CEC(cmol. kg-1 soil)	>25	10-25	5-10	<5
pH	>5.5	5.1-5.5	4.75-5.1	<4.75
Slope (%)	<30	—	—	≥30%
FI	>1.5	—	—	<1.5
ISS (%)	>9	7-9	5-7	<5

Table 2: Soil fertility limitations and capability classification units in reference [29].

(i) Level I: no or low limitations, (ii) Level II: not more than three moderate limitations, (iii) Level III: more than three moderate limitations associated with severe limitations, (iv) Level IV: more than one severe limitation.

Statistical analyses

Simple descriptive statistics was done using Excel 2016 and IBM SPSS Statistic 20 software to compare the soils under the different land use systems of Foumbot (Cameroon Western Highlands).

Results

Morphological characterization of soils under the different land use systems

Morphologically, the study soils are poorly developed as indicated by their AC profiles and developed as shown by their ABC profile. The profiles showed very similar morphological characteristics with the exception of ABC profile (Figure 2).

Profile PA1 in a primary forest was located on a flat slope on Andosols. The soil developed on pyroclastic materials with two horizons (A and C). The A horizon (0-25 cm) is loamy, dark grey (7.5YR2/1), crumby, small and larger roots, biological activities, average porosity, presence of partially weathered volcanic glass in the horizon, and a distinct transition with the C horizon (Figure 2). The C-horizon (25-160 cm) is sandy, very dark grey (7.5YR2.5/1), few fine roots, absence of biological activities, low porosity, average friability, presence of weathered volcanic cinders and other pyroclastic materials (Figure 2). Profile PA2 in tillage land use system was located on a gentle slope on Andosols. The soil developed on pyroclastic materials with two horizons (A and C). This profile is morphologically similar to PA1, with the exception of an Ap surface horizon resulting from cultivation, tillage and human activities. Profile PA3 in a burned land use system was located on a gentle slope on Andosols. The soil developed on pyroclastic materials with horizons A and C. It is morphologically similar to PA1, but thinner. Profile PA4 in a fertilized farm was located on a flat slope on Andosols. It has same parent material as profile PA1, with horizons A and C. This profile is morphologically similar to PA1, with the exception of an Ap surface horizon. Profile PA5 in fallow land use system was located on a gentle slope on Andosols. It developed on pyroclastic materials, with three horizons (A, BC and B). The A horizon (0-40 cm) is sandy, crumby, dark grey (7.5YR2/1), presence of small and large roots, presence of biological activities, high porosity, friable, presence of partially weathered volcanic glass, and a distinct transition with the BC horizon. The BC horizon at 40-60 cm is silty-sandy, reddish dark (5YR3/3), with very few roots, pyroclastic fragments, with a distinct and regular transition with the B-horizon.

The B-horizon at 60-160 (cm) is silty clay, light brown (7.5YR6/4), massive, absence of roots and biological activities, low porosity, and high compaction.

Figure 2: Presentation of soil profiles of the studied area (PA1, PA2, PA3, PA4 and PA5) and their land use systems (P0, T, B, FF and F).

Variation of soil Physico-chemical properties under the different land use systems

Descriptive analyses were carried out on soil characteristics of the five land use systems as shown in Tables 3 and 4.

Variation of soil physical properties under the different land use systems

The physical properties of the soils under different land use systems are presented in Table 3. The results showed that silt and clay are the dominant particle fractions in the studied soils with mean values of 51.03% and 28.73% respectively. Clay fractions increased in tillage (T) by 30%, and decreased in Fertilized Farm (FF) 27% compared to P0 (29%). It also decreased in Fallow (F) with 25 and 31% compared to tillage. Sand is the least particle size (21%); it decreases to 18.5% and 18, 2% in B and F land use systems respectively. Results showed that the soils had low bulk density values ranging from 0.50 to 1.0 g/cm^3 with mean values of 0.71, 0.76, 0.80, 0.86, and 1.0 g/cm^3 for burned, reference, fallow, fertilized farm and tillage land use systems respectively (Table 3). The burning and fallow management practices (0.71 and 0.76 g/cm^3) are capable of decreasing soil bulk density while tillage improves it (1.0 g/cm^3).

The studied soils had high structural stability (SSI > 9). This structural stability range from (11.11 to 14.90%) with mean values of 11.11, 11.80, 13.50, 14.35 and 14.90% in burned, tillage, fertilized farm, fallow, and reference land use systems respectively (Table 3).

Land use systems	Statistical parameter	%Sand	%Silt	%Clay	TC	BD(Mg/m^3)	%SSI
P0 (n=1)	Mean	20	54,50	25.5	Silty loam	1	14.9
T (n=3)	Mean	20.16	48.83	30	Loam	0.75	11.8
	SD	3.25	4.9	1.32		0.32	2.42
	Min	17	46	28.5		0.5	10
	Max	23.5	54.5	31		0.7	11.57
	CV (%)	16.12	10	4.4		42.6	20.5
B (n=3)	Mean	18.5	52.16	29.33	Silty loam	0.72	11.11
	SD	4.92	4.72	0.28		0.34	2.34
	Min	13	48.5	29		0.4	9.9
	Max	22.5	57.5	29.5		0.7	11
	CV (%)	26.6	9.09	0.95		47.2	21
FF (n=3)	Mean	23.66	50.5	27.83	Silty loam	0.86	13.5
	SD	2.46	3.04	4.04		0.25	2.59
	Min	22	47	25.5		0.7	12.6
	Max	26.5	52.5	32.5		0.8	13.2
	CV (%)	10.39	6.01	14.51		9.6	19.18
F(n=3)	Mean	18.66	51.5	28.83	Silty loam	0.9	14.37
	SD	1.25	3.04	2.51		0.29	2.67
	Min	17.5	48	26.5		0.74	13.5
	Max	20	53.5	31.5		0.9	14.5
	CV (%)	6.6	5.6	8.7		32.2	18.58

Table 3: Soil physical characteristics under the different land use systems.

P0: reference land use system, B: burned land use system, TC: textural class, BD: bulk density, SSI: soil structural stability indices, Min: minimum, Max: maximum, SD: standard deviation, CV: coefficient of variation.

Variation of soil chemical properties under the different land use systems

Results of analyses for the soil chemical properties of the five land use systems are presented in Table 4.

Soil organic matter was found to be very high, ranging from 9.0% to 12.0% with mean values of 9.16, 9.23, 10.63, 11.50, and 12.0% for burned, tillage, fertilized, fallow and reference land use systems respectively (Figure 3). The soil organic matter decreases slightly from 12.0% in the reference to 10.63% in fertilized land use system, and abruptly in burned and tillage land use system (9.16 and 9.23%) respectively. Inversely, it increased in fallow by 11.50% compared to tillage, burned and fertilized (Table 4).

The total nitrogen content of the soil was low to high (N<1%). The total nitrogen ranges from 0.10% to 0.40%. It therefore decreased significantly from 0.30% in reference to 0.10% in tillage and 0.20% in burned. Inversely, it increased significantly in fallow.

The soil valuable P was low with values ranging from 7.70 to 57.0 mg/kg and with mean values of 9.90, 17.16, 28.0, 38.0 and 51.8 mg/kg for burned, tillage, fallow, reference and the fertilized sites respectively (Figure 3).

Land use systems	Statisticalpa-rameter	pH	%OM	%Tot N	Ava P (mg/kg)	C/N	CEC(c-mol. kg-^{1}soil)	Ca^{2+}(col. kg-^{1}soil)	Mg^{2+}(col. kg^{-1}soil)	k^{+}(cmol. kg^{-1}soil)	Na^{+}(cmol. kg^{-1}soil)	TEB (cmol. kg^{-1} soil)
P0(n=1)	Mean	5.7	12	0.3	38	23	37	3.2	2	1.6	0.4	7.2
T (n=3)	Mean	5.1	9.23	0.1	17.16	53.6	20	2.53	0.76	0.56	0.2	4.1
	SD	1.59	2.14	0.22	2.92	5.17	3.16	1.12	0.61	0.52	0.31	1.43
	Min	5	9	0.1	16.5	52.2	18	2.5	0.7	0.5	0.2	3.2
	Max	5.2	9.5	0.1	18.5	55.2	22	2.6	0.8	0.6	0.2	5
	CV (%)	31	23.2	80	17	9.6	15.8	44.2	80.2	92.8	95	34
B (n=3)	Mean	5.63	9.16	0.26	9.9	27.66	31.33	3.4	1.31	0.2	0.17	5.08
	SD	1.67	2.14	0.36	3.14	3.71	4	1.3	0.8	0.31	0.29	1.59
	Min	5.3	9	0.1	7.7	14	28	3	0.96	0.12	0.17	4.16
	Max	6	9.4	0.4	13.5	46	37.1	4	1.68	0.29	0.18	6
	CV (%)	29	23.4	75	32	13.4	12.6	38.2	61.5	94	96	31.2
FF (n=3)	Mean	5.33	10.63	0.36	51.83	17.2	26.66	4.2	0.96	1.46	0.26	6.88
	SD	1.63	2.3	0.42	5.13	3	3.64	1.38	0.15	0.75	0.05	1.85
	Min	5.2	10.5	0.3	47.5	15.2	25.5	2.6	0.8	0.6	0.2	5.86
	Max	5.4	10.9	0.4	57.5	21.1	28	5	1.1	2	0.3	7.9
	CV (%)	30	21.6	65	10	17	13.6	33,0	16	51	19	26.9
F (n=3)	Mean	5.4	11.5	0.2	28.5	33.4	29.2	2.83	1.26	1.23	0.23	5.55
	SD	1.64	2.4	0.31	4	4.08	3.99	0.28	0.57	0.64	0.05	1.66
	Min	5.2	11.1	0.2	24.5	32.2	25.6	2.5	0.6	50	0.2	4.8
	Max	5.6	11.8	0.2	33.5	34.3	33.5	3	1.6	1.7	0.3	6.3
	CV (%)	30	21	82	13.12	12.23	14	10	45	52	22	30

Table 4: Soil chemical characteristics under the different land use systems.

P0: primary reference forest, T: tillage land use system, B: burned land use system, FF: fertilized land use system, F: fallow land use system, TEB: total exchangeable bases, OM: organic matter, N: total nitrogen, C/N: mineralization factor, avail. P: available phosphorus, CEC: cation exchange capacity, Min: minimum, Max: maximum, SD: standard deviation, CV: coefficient of variation.

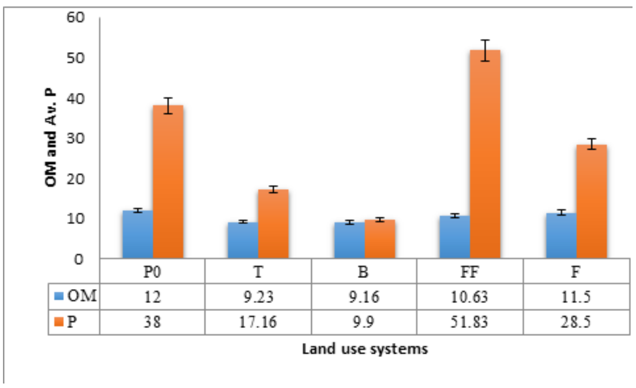

Figure 3: Variation of soil organic matter and available P under the different land use systems.

The studied soils were acidic (pH-H_2O 5.00 to 5.4), except for burning land use system with weak acid soils (mean value of 6.0). This acidity increased slightly from reference land use system (pH 5.70) to tillage (pH 5.10) and fertilized farm (pH 5.33), but decreased abruptly in burning (pH 6.0), as seen in Table 4.

Cation Exchange Capacity (CEC) was high with values ranging from 18.0 to 37.10 (cmol.kg^{-1}soil) with mean values of 20.0, 26.6, 29.20, 31.3 and 37.0 (cmol.kg^{-1}soil), for tillage, fertilized, fallow, burned and reference land use systems respectively (Figure 4). The highest value was in the reference land use system (38.0 cmol.kg^{-1}soil). It decreased significantly in tillage (9.90) and in burned land use system (17.16), but increase in fallow (28.0) and fertilized land use systems (38.0 cmol.kg^{-1}soil).

The sum of exchangeable bases was moderate with values ranging from 4.10 to 7.22 (cmol.kg^{-1}soil), with mean values of 4.10, 5.0, 5.55, 6.88 and 7.22 (cmol.kg^{-1}soil) for tillage, burned, fallow, fertilized and reference land use systems respectively.

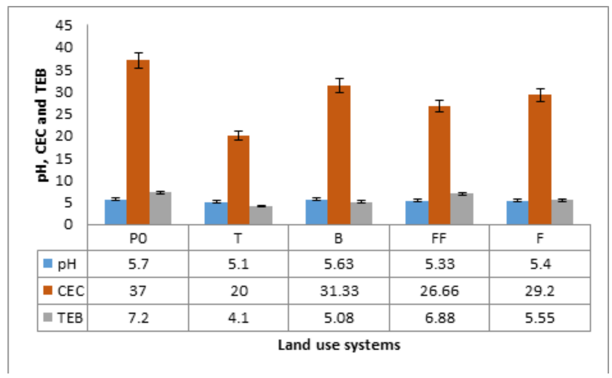

Figure 4: Variation of soil pH, CEC and TEB under the different land use systems.

The most abundant exchangeable cation in the soil was Ca^{2+} (2.50 to 5.0 cmol.kg^{-1}soil), followed by Mg^{2+} (0.60 to 2.00 cmol.kg^{-1}soil), K^{+} (0.12 to 2.00 cmol.kg^{-1}soil) and Na^{+} the least (0.17 to 0.40 cmol. kg^{-1}soil) as seen in Table 4.

Land use systems	Statistic parameter	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	TEB	Ca/Mg	Mg/K	TEB/CEC	TN/pH water
P0 (n=1)	Mean	3.2	2	1.6	0.4	7.2	1.6	1.25	19	0.05
T(n=3)	Mean	2.53	0.76	0.6	0.2	4.1	3.32	1.35	20	0.01
	SD	1.12	0.61	0.5	0.3	1.43	1.28	0.81	3.16	0.07
	Min	2.5	0.7	0.5	0.2	3.2	1.2	0.3	8	0.002
	Max	2.6	0.8	0.6	0.2	5	2.3	0.5	12	0.003
	CV (%)	44	80.2	93	80	34	38	60	15.8	70
B(n=3)	Mean	3.4	1.31	0.2	0.2	5.08	2.6	6.55	16	0.04
	SD	1.3	0.8	0.3	0.3	1.59	1.14	1.8	2.82	0.14
	Min	3	0.96	0.1	0.2	4.16	0.7	2.3	6.5	0.01
	Max	4	1.68	0.3	0.2	6	1.8	3	8.6	0.03
	CV (%)	38	61.5	96	84	31.2	43.8	27.6	17.62	80
FF(n=3)	Mean	4.2	0.96	1.5	0.3	6.88	4.37	0.65	25	0.06
	SD	1.38	0.15	0.8	0.1	1.85	1.47	0.57	1.87	0.17
	Min	2.6	0.8	0.6	0.2	5.86	1.6	0.15	10	0.02
	Max	5	1.1	2	0.3	7.9	2.9	0.5	15	0.03
	CV (%)	33	16	51	19	26.9	33.7	87.7	7.48	83
F(n=3)	Mean	2.83	1.26	1.2	0.2	5.55	2.24	1.02	19	0.03
	SD	0.28	0.57	0.6	0.1	1.66	1.05	0.71	3.08	0.12
	Min	2.5	0.6	0.5	0.2	4.8	0.7	0.2	7.5	0.01
	Max	3	1.6	1.7	0.3	6.3	1.8	1.2	17	0.03
	CV (%)	10	45	52	22	30	47.2	70	16	82

Table 5: Soil nutrient ratios and fertility indices under the different land use systems.

CEC: Cation exchange capacity, TEB: total exchangeable bases, Min: minimum, Max: maximum, SD: standard deviation, CV: coefficient of variation.

Soil nutrient status

Soil nutrient ratios in the studied land use systems are presented in Table 5. The C/N ratios were low to very high, ranging from 9.11 to 55.71%. The C/N mineralization ratio was greater than 20 in most of the soils (53.0, 33.0, 27.0, and 23.0%) in tillage, fallow, burned and primary forest respectively. The lowest C/N ratio was seen in the fertilized farm (17. 20%). The Ca/Mg ratio ranges between 2 to 4 and Mg/K range from 1 to 4. The fertilized farm, tillage, burned and fallow land use systems of the studied soils have Ca/Mg ratio of 4.37, 3.32, 2.60 and 2.24 respectively. As for Mg/K ratio, the fertilized land use system portrays an unfavorable ratio of 0.65 while the burned land use systems present ratios greater than 4 (6.55). Tillage, reference and fallow land use systems show good Mg/K nutrient ratios of 1.35, 1.25 and 1.02. The calculation of Ca/Mg/K equilibrium balance shows that, these soils have excess Ca^{2+} and are close to the optimal equilibrium (Table 5). Soils under burned land (70/26/4), tillage (66/20/14) and fertilized land use systems (63/14/22) respectively have excess Ca^{2+} and are almost close to cationic balance while reference (47/29/23) and fallow (54/24/23) presents ratios below standard.

Objectively, the basic cations (K^{+} and Na^{+}) decreased while Ca^{2+} and Mg^{2+} increased over the land use systems.

The N/P ratio (nitrogen mineralization indices) was low in tillage, and high in the remaining soils. The Forestier's fertility indices were extremely low (<1) for all the land use systems.

Discussion

Morphological characterization and classification of the studied soils

Morphologically, the studied soils are poorly developed as indicated by their AC profiles except for PA5 with a developed ABC profile. The similarities in soil morphological characteristics could be as a result of unique or similar parent materials, climate, topography, time, and vegetation. The reddish dark and light brown color in the horizon BC and C of the PA5 may be due to the presence of sesquioxides as color is a function of chemical and mineralogical composition as well as textural make up of soil, and conditioned by topographic position and moisture regime.

Generally, the morphological descriptions confer to andic properties with andic horizon. As a result, the soil belongs to the Andosols Reference Soil Group (RSG). The presence of partially weathered pyroclastic materials and volcanic glass attribute to these soils a vitric qualifier. The dark grey color and acidic pH range of 5.0 to 6.0 reveal the presence of silica and allophane in the soils, thus referring to as silandic andosols. By attributing a vitric qualifier to the soil reference group, the studied soils were classified as Vitric Silandic Andosols.

Influence of land use systems on soil physicochemical properties

In terms of soil physical properties, the low textural variation in the studied land use systems could be attributed to the homogeneity of the soils which resulted from similarity in volcanic parent material and climate within the study area. This is in conformity with the findings of [32-34]. The high silt content in tillage is in accordance with the findings of [30-35] on soils of West Cameroon and Southeastern Nigeria. The high silt is as a result of physically degraded, high degree and extent of weathering and leaching of the soils. The conversion of forest to farm land is known to deteriorate soil texture and making the land more susceptible to erosion due to soil structure disturbance. This result is in harmony with [36] who also recorded different soil texture types for different land use systems. Sand particles decreases in tillage land use system are probably due to farm preparations, tillage practices and differential segregation by erosion. The lowest sand content in the burned land use system result from the effects of fire, heat and segregation on soil coarse sand to fine particles. Generally, the soil texture ranged from loam to silty loam, which is very good for agriculture.

The high bulk density (1.0g/m^3) in tillage may result from the combined influence of soil ploughing during farm preparations, roots distribution, repeated sowing and harvesting, and human activities on the farm. These factors may lead to soil compaction resulting to higher BD as the duration of practice increases [37]. Moreover, the average BD (0.71g/m^3) in the burned land use system may result from the mild effects of fire on soil organic matter and microbial activities binding the soil. Since SOM holds sand, silt and clay particles into aggregates, a loss of SOM lead to loss of soil structure and bulk density [38]. These results contradict the findings of [6] in West Cameroon. This complexity can be understood as the duration and different intensity of fire on soil properties. The lowest bulk density in the fallow and reference land use systems (0.76g/m^3 and 0.80g/m^3) respectively, could be attributed to their richness in organic matter. This is because SOM holds sand, silt and clay resulting to good soil structures and aggregations.

The high SSI of these soils gives high risk of structural degradability, high fertility by reducing the rate of water infiltration, which determines water availability to plants. Structural stable soils have high capacity of internal cohesion of aggregates.

In terms of soil chemical properties, soils rich in organic matter have physical phases favourable for plant development because organic matter plays a physical role in the soil for cohesion, structure, porosity, water retention and storage [39]. The very high organic matter content in these land use systems could be associated to high level of organic materials on the surface horizons, low mineralization and low climatic activities. Also, [40] reported that land use system, landscape position, and fluvial depositions could result to high variation of organic matter in pedons. The OM was slightly higher than the results of [7], which stood at 2.77% to 4.73% SOC in North Cameroon. The burning practice significantly reduces soil organic matter (12.0 to 9.16%) by calcination. This reduction had been reported by [6] at a higher reduction rate of 87.7%. This high and severe organic matter reduction might have resulted from high fire intensity than in the current study. A significant reduction in organic matter in tillage and fertilized land use systems (12.0 to 9.23% and 12.0 to 10.63% respectively) is dependent on organic material deposit, mineralization and plant nutrient uptake. The effects of prolong tillage aggravates organic matter oxidation. This reduction could further result from the microbial oxidation of the previously protected soil organic compounds which were destroyed by cultivation. These results are in conformity with the findings of [41-46] that both reported less organic matter in tillage than in forest soils. However, the conversion of primary forest covers into fertilized cultivated lands had affected soil chemical properties. For instance, increasing acidification of soils in the fertilized land use system could retard vegetation growth and soil organic carbon accumulation. A study by [9] also reported that alteration of dense forests to cultivated lands brought about 25% reduction in soil organic carbon in a dry mountainous forest in Northern Ethopia. This is because; forests play a key role in the global carbon cycle by capturing atmospheric C through the processes of photosynthesis and by converting it into forest biomass [47]. Sustainably, the increase in organic matter in fallow could be due to inputs and low rate of litter decay and may be sustainable with the addition of organic residues in 5 to 15 years fallow [48-49]. Objectively, the reduction in soil organic matter percentage negatively influences fertility of the study soils since it is known to play a key role in exchangeable cations retention. This reduction could also lead to increase soil erodibility, transport of soil nutrient and soil fertility decline.

The total nitrogen content of the studied soils was low when compared with the ratings of [50]. This could be associated with the climatic condition of the study area, which influences leaching and high mineralization. The high percentage of total nitrogen in the burned land use system may be from the burning of grasses and surface litter that produce ash rich in nitrogen and other major nutrients. The significant increase in nitrogen in the fertilizer land use system result from intense application of NPK fertilizers in tomatoes farm. The low N content in tillage may be due to the continuous cultivation and poor management practices coupled with rapid mineralization of organic substances and insufficient organic input application as reported [51].

Generally, available phosphorus of the studied soils was low when compared with ratings. The low available phosphorus level uncounted in the study area collaborate with the findings of [52] who remarked that most Cameroonian soils have low phosphate reserves due to high phosphorus fixation. The significant P increase in the fertilized land use system may result from the application of ammonium phosphate and NPK fertilizers in farmland. The high amount of phosphorus in the burned land use system may result from the liming action of residual ash thus, increase phosphorus availability to plants. The phosphorus content in the fallow land use system may result from higher organic matter concentration in this land use system, retained and immobilized by microbes in the litter layers of forests with little or no nutrient export by crops. This result agrees with the findings of [7] in Cameroon Western Highlands. The soil available P deficiency in our study area may be due to the inherent low P status of the parent material and erosion loss. This could also be due to low soil pH causing P-fixation. These facts confirm the findings of [53] who reported that the available P in most soils of the North West region, Cameroon is low due to P-fixation, crop harvest, and water erosion.

The pH (H2O) was moderate to strong acidic for soils across the studied land-uses. The acidity was determined by the ratings of [40]. The pH value (5.10 to 6.0) across the five land use systems was almost homogenous in acidity as reported by [36] who also revealed homogenous and moderate acidity pH values in different land use systems at the southern parts of the Mount Cameroon National Park (MCNP). The low variations could be associated to a similar parent material (pyroclastic materials) which was earlier reported by [32]. The moderate to strongly acidic reaction is a characteristic of soils of Western Cameroon and may result from acidic nature of parent rocks, coupled with the influence of leached profile under high rainfall. Soil pH is the most important chemical characteristic of a soil solution. The lowest pH values (pH 5.10) and strong acidity in the tillage land use system suggest possible low availability of both macro and micro plant nutrients for uptake by crops. The low pH may be attributed to the remover of soil coverage through tillage practice, leading to the leaching of bases, removal of bases through crop harvests, resulting to soil acidification. The low pH value in the fertilized land use system could result from the application of ammonium sulphate and NPK fertilizers in tomatoes farm, leading to high acidity. The soil acidity also increases in tillage management system compared to the primary forest (pH 4.62 to 4.42), inducing decrease in agricultural productivity. Even 10 years of fallow, management system is not enough to improve the strong acidity induced by tillage practice.

Land use systems had greater impacts on CEC of the study soils compared to the reference. The reduction in CEC in tillage and fertilized land use systems (37 to 20 cmol.kg^{-1}soil and 37 to 17 cmol.kg^{-1}soil) respectively leads to a decline in soil fertility especially as the duration of practice increases. The least CEC in tillage and fertilized farm could result from less soil organic matter concentration. The continuous cultivation and removal of crop residue coupled with severe soil erosion leads to loss of exchangeable cations. The high CEC content in the burning land use system (31.3 cmol.kg^{-1}soil) might be consistent with the release of base cations during calcination [54-57]. These results do not conform to the works of [6,7] in Western Cameroon. This is because fire intensity plays a key role in the calcination and mineralization of plant residues. The fallow management system restored soil CEC lost in tillage and fertilized farm (20 to 33.5 cmol.kg^{-1}soil and 17 to 33.5 cmol.kg^{-1}soil) respectively. This shows that 10 years of fallow practice is capable of restoring some of the soil nutrients lost through erosion and crop harvest. The difference observed in the Total Exchangeable Bases (TEB) could be attributed to leaching, runoff and plant uptake. TThis agreed with the findings of [54]. The high TEB especially Ca2+ in burned land use system could result from the burning of vegetation and subsequent plant decomposition as reported by [55]. According to the nutrient deficiency model, this high TEB is not sustainable because it is easily lost by erosion, runoff, leaching and some even volatized. The low TEB in tillage may result from soil cultivation, erosion, runoff, leaching and some nutrients lost through plant harvest. The time of soil nutrient depletion is dependent on climate, soil properties, topography, and management practices. Appropriate soil conservation practice is one of the sustainable ways of maintaining soil nutrients.

Soil nutrient ratios and fertility indices under the different land use systems

The availability of nutrients for plants uptake depends not only upon absolute levels of nutrients but also on the nutrient ratios. Nutrient imbalances influence nutrient uptake by inducing deficiencies of nutrients, which may be present in the soil in good quantities [58]. It is therefore vital to consider the individual nutrient ratios like Ca/Mg ratio and Mg/K ratio, which are indicators of nutrient uptake. The C/N ratios in tillage, fallow, burned and primary forest respectively, reflects a very low rate of mineralization caused by low nitrogen. Mineralization is slow in this soil group and allows only a small amount of mineral nitrogen to the soil [59-61]. The Ca/Mg ratio range of 2 to 4 and Mg/K range of 1 to 4 are considered favorable for most tropical crops. The results showed that Ca/Mg ratio of the soils is lower than the optimum range in the primary forest (1.60) which can limit Mg uptake by plants. Fertilized farm, tillage, burned and fallow land use systems have Ca/Mg ratio of 4.37, 3.32, 2.60 and 2.24 respectively, which are within the optimum range. As for Mg/K ratio, the fertilized land use system portrays an unfavorable ratio of 0.65 which can limit K uptake, while in the burned land use system the ratio is greater than 4 (6.55) which can inhibit K uptake by plants. Tillage, reference and fallow land use systems show good Mg/K nutrient ratios of 1.35, 1.25 and 1.02 respectively without antagonism. From these results, it is apparent that, nutrient imbalances observed in this study will influence nutrient availability which determines the crop potential yield and can be improved by manuring, application of inorganic fertilizers and crop rotation [62]. The calculation of cationic balance of Dabin, Ca/Mg/K shows that these soils have excess Ca^{2+} and are close to the ideal equilibrium of 76/18/6 for the three basic cations. Soils under burned land (70/26/4), tillage (66/20/14) and fertilized land use system (63/14/22) respectively have excess Ca^{2+} and are almost close to cationic balance while reference (47/29/23) and fallow (54/24/23) presents ratios below standard. This indicates a balance in absorption and good assimilation by plant roots [63], while the remaining soils show deficits in K^+ and Mg^{2+}. This means that the texture complex is essentially dominated by Ca^{2+}. This richness of the texture in Ca^{2+} may explain the low pH of these soils. Globally, the basic cations (K^+, Na^+) decreased while Ca^{2+} and Mg^{2+} increased over the land use systems and can be attributed to soil pH. Low pH values in soils influence the availability of K^+, Ca^{2+} and Mg^{2+}, which are generally not available for plants uptake in strong acid soils since they may have been partially leached out of the soil. The N-pH ratios divide the study soils into two fertility classes: good fertility soils and moderate fertility soils. Soils under primary forest, burned land and fallow land use systems represent good fertility soils while tillage and fertilized farm are soils with moderate fertility. The limitation of the moderate fertility soils is the low pH of 5.1 in tillage and 5.3 in fertilized land use systems. The low pH values observed in this study may therefore affect the nutrient retention and fertility of the soils. The N/P ratio (nitrogen mineralization indices) was low in tillage, and high in the remaining soils. The high values may reveal potential risk of nitrogen deficiency and vice versa [64].

Soil fertility capability classification

The statistical analysis of fertility parameters as well as the balance between these parameters made it possible to assess the current fertility status of the soils under different land use systems. The criteria of assessment were grouped into four fertility levels in Tables 2 and 6, according to [65-66]. According to the fertility evaluation criteria in Table 6, the studied soils were classified into three (03) fertility levels (very good, good and average fertile soils). Level I (40% of the studied soils) includes soils with very good fertility such as the reference (P0) and fallow land use systems with little phosphorus limitation. This limitation can be corrected with phosphate rocks and ammonium phosphate fertilizers. Level II includes soils with good fertility (40% of the studied soils) including the fertilized land use system with moderate pH and leaching potential limitation. These limitations can be corrected by liming, integrated fertilization and minimum tillage (Table 6). Moreover, minimum tillage. Level III (20% of the studied soils) includes soils with average fertility such as tillage and burned land use systems. These soils have moderate to severe P, K^+, pH, CEC, SSI and leaching limitations. It is necessary to provide these soils with phosphate fertilizers, as well as fallowing for about 10 years to regain fertility, and minimum to zero tillage.

Land use systems	`OM (%)	N (%)	P(mg Kg-1)	K(cmol/kg of soil/100)	CEC(cmol/kg of soil)	TEB(cmol/kg of soil)	pH	SSI	Slope (%)	Leaching Potential	Texture	Fertility level	Limiting factors
P0	I	I	I	I	I	II	I	I	I	I	I	Very good	_
T	I	I	II	II	II	III	II	I	I	IV	I	Average	P, K, pH, CEC, and leaching
B	I	I	II	II	I	II	I	II	I	III	I	Average	P, K, pH, CEC, leaching
FF	I	I	I	I	I	II	II	I	I	III	I	Good	pH and leaching
F	I	I	I	I	I	II	I	I	I	I	I	Very good	_

Table 6: Soil fertility evaluation under the different land use systems.

CEC: cation exchange capacity, TEB: total exchangeable bases, SSI: soil structural stability indices.

Landscape, soil and climatic characteristics	P0		T		B		FF		F	
	Maize	beans	Maize	Beans	Maize	beans	Maize	beans	Maize	Beans
Climate during crop cycle (c)										
Precipitation (mm)	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1
Mean temperature (0C)	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1
Topography (t)										
Slope (%)	S1-1	S1-1	S1-1	S1-1	S2	S2	S1-1	S1-1	S1-1	S1-1
Altitude (m)	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	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	S1-0	S1-0
Drainage	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0
Soil physical characteristics (s)										
Coarse fragments (%)	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
Soil texture	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0
Soil fertility (f)										
pH	S2	S2	S3	S3	S1	S1	S1	S1	S2	S2
SEB (cmolc+kg^{-1})	S2	S2	S2	S2	S1	S1	S1	S1	S2	S2
CEC (cmolc+kg^{-1})	S1-0	S1-0	S1-1	S1-1	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0
SOM (%)	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0
Base saturation (%)	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2
Salinity (n)										
ESP (%)	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0
Suitability class										
Class	S2fS2f	S2fS2f	S2fS3f	S2fS3f	S2fS2t	S2fS2t	S2f	S2f	S2fS2f	S2fS2f

Table 7: Suitability of studied soils for the production of maize and beans.

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%)..

Suitability of soils for the cultivation of maize and beans

The fertility status of these soils was studied through land evaluation using simple limitation and parametric methods. This process enables the identification of potential soil fertility constraints, thus provides valuable information in designing appropriate soil management strategies for sustainable crop production. The studied soils are widely used for the cultivation of maize and beans [59, 67] and are very suitable for the cultivation of these crops with the exception of soils under tillage and fertilized land use with high acidity and marginal suitability (Table 7).

Soils under burned land use system were suitable for the cultivation of maize and beans with high suitable precipitation, temperature, altitude of <1100 m, coarse fragments ranging from 3-15 %, soil depth (>100 mm), soil pH (5.5-5.8), CEC (>24 cmolc+kg^{-1}), organic carbon (>2%), good drainage and gentle slope (5-8%) as the only moderate limitation. Soils under fallow were very suitable for the cultivation of maize and beans with high suitable precipitation, temperature, altitude of <1100 m, stable slope (2-5%), coarse fragments ranging from 3-15 mm, soil depth (>100 mm), soil pH (5.5-5.8), CEC (>24 cmolc+kg^{-1}), organic carbon (>2 %) and good drainage. Soils under fertilized land use system were suitable for the cultivation of maize and beans with high suitable precipitation, temperature, altitude of <1100 m, stable slope (2-5%), coarse fragments ranging from 3-15(mm), soil depth (>100), CEC (>24 cmolc+kg^{-1}), organic carbon (>2 %), good drainage and soil pH (5.2-5.5) as the only moderate limitation for the cultivation of these crops. Soils under tillage land use system were moderately suitable for the cultivation of maize and beans with high suitable precipitation, temperature, altitude of <1100, stable slope (2-5%), coarse fragments ranging from 3-15(mm), soil depth (>100 mm), organic carbon (>2), good drainage, and soil pH (5.2-5.5) and CEC (>24 cmolc+kg^{-1}) as moderate limitations for the cultivation of maize and beans. These results are consistent with those already documented in Foumbot and the Western Highlands of Cameroon [67-70].

Conclusion

The objective of this work was to determine the effects of different land use systems on soil physico-chemical properties, nutrient status and fertility classification in order to understand the causes of soil fertility and crop productivity decrease in Foumbot (Cameroon Western Highlands). Soil morphology and physico-chemical characteristics reveal that the studied soil is Vitric Silandic Andosols. Most soil properties had an irregular pattern of decrease or increase in the different land use systems. The physico-chemical results showed that tillage practice is a significant driving force for soil fertility decline. It significantly reduces soil organic matter, total nitrogen, available phosphorus, and CEC, but increases soil acidity and compaction; the chemical and physical properties that negatively affect soil quality. Burning practice has mitigated influences on soil quality; the severe reduction of soil organic matter, total nitrogen and aggregate stability, which negatively affect soil quality. Inversely, the net increase in the soil pH, CEC and sum of exchangeable cations contribute to improve significantly the soil quality. However, this improvement lasts only for a short period because water erosion and it subsequent nutrients leaching leads to soil impoverishment. Fertilizer application is a driving force for soil fertility decline. It increases soil acidity, reduces soil organic matter, which negatively affect soil quality. Inversely, fertilizers application increases soil total nitrogen, phosphorus and total exchangeable bases but the improvement is not sustainable because water erosion and it subsequent nutrients leaching leads to soil impoverishment. Fallow practice significantly improves soil quality. It sustainably improves soil organic matter, CEC and sum of the exchangeable cations, total nitrogen and soil aggregates. Nevertheless, even 10 years of fallow is not enough to regenerate the fertility lost in tillage, burned and fertilized land use systems. The soil fertility capability classification of the studied area reveals three fertility classes, namely: very good fertile soils under fallow and reference land use systems, good fertile soils under fertilized land use system and average fertile soils under tillage and burned land use systems. The fertility assessment makes it possible to understand that the major problems of the studied soils are high acidity and low available phosphorus. Soils of the study area are very suitable for the cultivation of maize and beans except for tillage and fertilized soils with high acidity. To improve soil fertility in the studied area, emphases should be placed on promoting the use of sustainable land management practices like minimum tillage, fallow, liming, use of organic manure and integrated fertilization.

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Author's Contribution

Kunghe G, Azinwi Tamfuh P, Bitom D, Tematio P, Nguemezi C, Lionelle Estelle Mamdem, Moundjeu ED; Performed the experiment, analyzed and interpret the data, wrote and reviewed the paper.

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Conflict of Interest

The authors declare no conflict of interest regarding the publication of this paper.

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