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Variation in Total Soil Organic Carbon Stocks in Relation to Some Land Use Systems in the Bamenda Highlands, Cameroon

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Abstract

Climate change and food security are among the pressing challenges facing humanity in the 21st century. Soil organic carbon (SOC) stocks, total nitrogen (TN), texture, and bulk density (BD) are important soil properties, which control climate change. Three land use systems (smallholder farmlands, grazing lands, and forest lands) that coexist in the Bamenda Highlands (BH) influence ecosystem services and induce soil degradation with the loss of SOC. The objective of this study was to evaluate the variation of SOC and some soil physico-chemical properties as affected by the three land use systems (LUS). A total of 21 composite soil samples collected from 7 microclimatic zones of BH following "S" shape plots to the depth of 0 - 30 cm, were analysed for moisture content (MC), SOC, TN, BD, available phosphorus (Av.P), pH and texture. The results revealed that grazing land had the lowest mean sand content (40.79 ± 4.07). Mean MC, TN and SOC (%) content were significantly higher ($p < 0.05$) in forest land than those in the grazing land and smallholder farmlands. Conversely, BD and Av.P were significantly higher ($p < 0.05$) in smallholder farmlands than grazing and forest lands probably due to different litter accumulation and agricultural practices. Moisture content and TN revealed positive significant correlations ($p < 0.05$) with SOC, while BD and Av.P revealed negative significant correlations ($p < 0.05$). Mean SOC density in smallholder farmlands (132.91 ± 9.48 tC/ha) was the lowest among the three land use types. Losses in CO_2 equivalence, as a result of land use change from forest lands to smallholder farmlands were 137.33 t/ha while that from grazing lands to smallholder farmlands were 109.13 t/ha. Total organic carbon (TOC) stocks differed significantly ($p < 0.05$) from smallholder farmlands (10.73 Mt) to forest lands (91.13 Mt). A sustainable farming technique that enhances SOC sequestration and minimizes soil CO_2 emissions is therefore recommended to replace tillage ridges formation commonly practiced by smallholder farmers.

Keywords

Soil, Soil Organic Carbon, Land Use Systems, Bamenda Highlands, Soil CO_2 Emissions

1. Introduction

The two most pressing and interlinked challenges facing human and environmental sustainability in this 21st century are climate change and food security (Godfray et al., 2011). According to IPCC (2001), the accumulation of Carbon dioxide (CO_2) in the atmosphere is the leading factor attributed to be the basis of climate change. Efforts to achieve food security through intensification of agricultural activities contribute heavily to the accumulation of CO_2 in the atmosphere leading to the global climate change challenge. Climate change on the other hand, inflicts negative impacts on agricultural production. Carbon sequestration by oceans, plants and soils is the most economic viable option to limit the rising levels of CO_2 in the atmosphere (FAO, 2001). Land use 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 (SOM) (FAO, 2001). Yao et al. (2010) stated that soils can differ in physical properties based on land use types. These physical properties are crucial to root growth, infiltration, water and nutrient holding capacity (Zhang & Shangguan, 2016).

The livelihood of rural people in sub-Saharan Africa remains largely dependent on natural resources (Roe et al., 2009). Even so, natural as well as anthropogenic factors such as rainfall, temperature, farming practices and grazing, exert pressure on these natural resources leading to spatial and temporal scale changes on a landscape and bio-physico-chemical nature of the soil. In Cameroon, about 80% of the population is engaged in biodiversity related activities, most of which impact positively on the family revenue or on a greater extent, the national economy and foreign trade. Over 70% of the Cameroon population is engaged in agriculture (MINADER, 2015).

Conventional agricultural land use practices alter the soil organic carbon (SOC) availability, pH, nutrient availability and other chemical properties (Cookson et al., 2007) which, in turn, alter soil microbial community structure and function, thus, altering productivity. Farming practices in the Bamenda highlands include; complete overturn tillage with ridges formation, tillage without ridges formation, no till, and strip tillage. About 98% of smallholder famers in the Bamenda highlands are involved in complete overturn tillage with ridges formation. This tillage system also involves; slash and burn, burning of crop residues within tilled ridges, and heavy applications of agrochemicals such as mineral fertilizers and pesticides. These practices lead to reduction in the soil biodiversity, soil organic carbon storage, and increase in irreversible erosion of soil (Schiavon et al., 1995). Maize being the most staple crop in the Bamenda highlands is cultivated mainly through complete overturn tillage with or without formation of ridges.

Furthermore, Vermeulen et al. (2012) reported that agriculture was directly responsible for 14% of global annual greenhouse gas (GHG) emissions with an additional 17% of GHG emissions from conversion of forest lands to agricultural lands. Developing countries including Cameroon, accounted for about 3/4 of direct emissions and are expected to be the most rapidly growing emission sources in the future (FAO, 2011). CO_2, methane (CH_4) and nitrous oxide (N_2O) were identified as key GHGs that contribute towards global warming at 60%, 15% and 5%, respectively and are the gases most emitted from agricultural fields as a result of tillage and agricultural inputs practices (Watson et al., 1996). The concentrations of CO_2, CH_4 and N_2O in the atmosphere increase at 0.4%, 0.3% and 0.22% per year, respectively (Battle et al., 1996).

Although a consent exists that the resource use efficiency, climate change and food security challenges will exacerbate under the conventional agricultural practices, little is predicted about the magnitude of these adverse change over time in developing countries. This probably hinders the development and implementation of both essential and appropriate adaptation and mitigation measures/policies to increase the resilience of agricultural production systems. Quantification of SOC from soil is therefore needed for global modelling studies in the context of climate change (Li et al., 1997) and ecosystem modification to be implemented. Global, regional and local estimates of SOC from staple crop fields vary greatly with the assumptions made on the importance of different factors affecting the emissions. Hence, the need to estimate SOC stocks as a result of land use change before the deployment of any system that is aimed at facilitating climate change and food security predictions round the world. The main staple foods in the average African diet are cereals and the most common cereal in Cameroon is Maize (*Zea mays*). However, in spite of availability of a number of cereal varieties with improved yield potential, the productivity of staple cereal crops remains low, around 1 t/ha (WDR, 2007). Every year there is thus a critical shortage of cereals in many smallholder households, leading to high grain prices, hunger, undernourishment and widespread poverty. Therefore, the need to estimate SOC stocks from conventional cereal farming practices in Africa cannot be overemphasized.

This study was therefore aimed at estimating a baseline of total SOC stocks in smallholder farms, grazing and forest lands in the BH to aid future modelling of SOC stocks, and the development and implementation of appropriate mitigation and adaptation policies.

2. Materials and Methods

2.1. Study Area

This study was carried out in the Bamenda highlands (1,740,000 ha) of North

West Cameroon located between latitudes 5˚45'N and 9˚9'N and longitudes 9˚13'E and 11˚13'E (Tellen & Yerima, 2018; Manu et al., 2014). The BH has a great variation in topography from depressions of less than 400 m to mountains slightly more than 3000 m above sea level (Tellen & Yerima, 2018). The region counts 1,968,600 people in 2015 with a density of 114 persons/km^2. The Bamenda highlands comprise seven administrative divisions, of less than 200 km apart (Ndoh et al., 2016) (**Figure 1**). These highlands experience an equatorial climate of the Cameroon type with two major seasons: A long, wet season of eight months (March to October), and a short, dry season of four months from November to March (Tume et al., 2020). The average annual rainfall and temperature is 2675.2 mm and 22.3˚C respectively (Azinwi et al., 2018). The soils of the Bamenda highlands are predominantly ferralsols (Yerima & Van Ranst, 2005). Erosion, resulting from the topographic nature and torrential rainfall, is a major obstacle to sustaining the soil fertility.

2.2. Land Use (LU) Map

The subset of Landsat 7 (ETM+) scenes (band 1, 2, 3, 4, 5 and 7) with cloud cover less than five percent were obtained from 2020 Landsat ETM satellite images of the Bamenda Highlands and used for this study. These images are freely available from the United States Geological Survey (USGS) obtained using Earth Explorer (https://dds.cr.usgs.gov/). The images were geometrically corrected using 21 ground control points (GCPs), obtained from the field survey using the GPS device.

A supervised classification using maximum likelihood classification system with overall accuracy of 87.14% and kappa coefficient of 0.89, was conducted to classify the Landsat 7 (ETM+) image using the spectral signatures from the training data. Means and variances of classes were used to estimate probabilities and check on variability of brightness in each class. The classified images were smoothened twice with a 3 × 3-majority rule filter. Various forest lands, grazing lands, and farmland areas were extracted and from the classified image and added to give the total area for each of these classes. The tools used were; ENVI 4.7 and QGIS software, camara, and Global Positioning System (GPS).

2.3. Experimental Design

The main land use types in the BH were studied from the land use map and three typical land use systems (LUS) (smallholder farmlands, grazing land, and forestland) were selected. Detailed investigation was carried out to ascertain the history and current situation of the cultivated lands. The entire BH was divided into 7 microclimatic zones namely; cold, cloudy, misty, cool misty, warm, wet, and variable (warm wet, sunny) according to Tume et al. (2020). The smallholder farms were ploughed, fertilized and planted with mixed crops every year under conventional tillage and ridges formation for more than ten years. The grazing

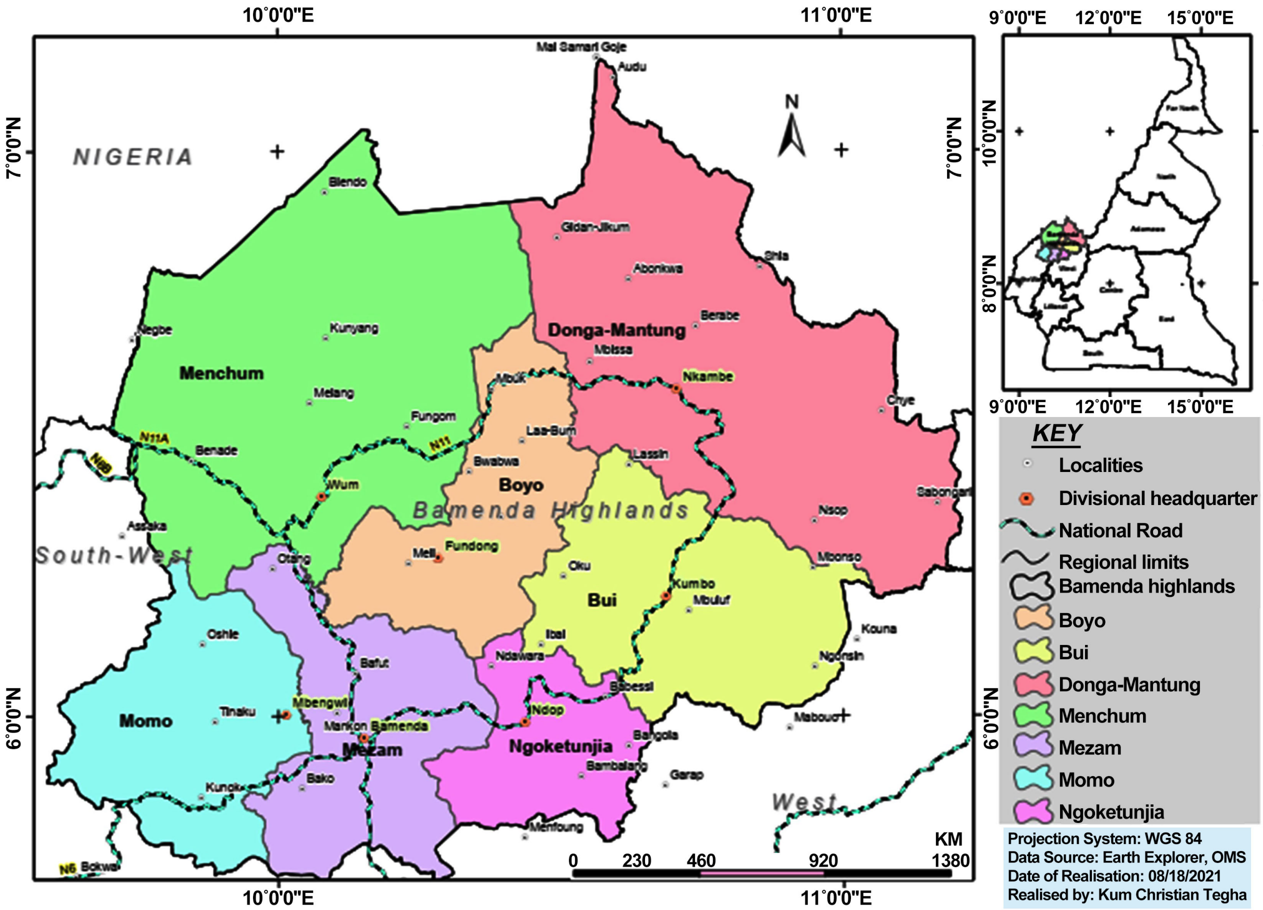

Figure 1. Map showing the location of Bamenda Highlands, Cameroon.

lands are natural savannah regularly grazed with cattle. The three land use types had similar geographic conditions, belonged to the same microclimatic zones with probably the same parent materials.

Fieldwork was carried out in November 2020. Three sampling plots of 50 × 50 m were identified using the method of Kum & Yinda (2016) for each of the three LUSs in the seven microclimatic zones of the BH. Soil samples were collected with the aid of a soil hand auger at soil depth of 30cm. The sampling plots of each LUS in a microclimatic zone were distributed according to an "S" shape to cover vertical and horizontal variations (Jiao et al., 2020). At each sampling plot, three soil samples were collected, following a diagonal transect across the plot and bulked to give a homogenous sample for that plot. The three bulked soil samples from the sampling plots of each of the LUSs (smallholder farmlands, grazing lands, and forest lands) gave a total of 63 soil samples for the entire BH.

2.4. Soil Sampling and Analysis

The collected soil samples were air-dried for two weeks, ground in a ceramic mortar using a pestle, and sieved through a 2 mm sieve. The three soil samples from a land use system within the same microclimatic zone were thoroughly mixed to give a composite sample for that LUS in that microclimatic zone. A total of 21 composite samples (7 for each of the three LUS) were sent for analysis at the Laboratory of Soil Analysis and Chemistry of the Environment (LABASCE) of the Faculty of Agronomy and Agricultural Sciences, University of Dschang, Cameroon. The particle size distribution and textural class were determined using Robinson's pipette method (FAO, 2006). The SOC was measured by the Walkley-Black method (1934). The pH (Potassium chloride (KCl)) was determined according to McLean (1982) in a soil/Potasium Chloride ratio of 1:2.5. Total nitrogen and available phosphorous were measured using Kjeldahl and concentrated nitric acid methods respectively (Bremner & Mulvaney, 1982; Olsen & Sommers, 1980). Sample for soil bulk density and moisture content analysis were collected using a metal core. The volume of the core was determined using Equation (1):

$$V = \pi r^2 h\left(\text{cm}^3\right) \tag{1}$$

where V = volume of core (cm^3); π = 3.14; r = radius = diameter/2 (cm); and h = height (cm).

The soil moisture content and bulk density were determined by noting the difference in weight of fresh soil samples and oven dried soil samples at temperatures of 105˚C for 24 hours. The fresh and dry weights of the samples were taken using an electronic scale balance. Soil bulk density and moisture content were estimated using Equation (2) and Equation (3) respectively.

$$BD = M/V \tag{2}$$

where BD = bulk density, M = mass of oven dry soil (g), and V = volume of core (cm^3).

$$MC(\%) = 100(fw - dw)/dw \tag{3}$$

where MC (%) = soil moisture content in percentage, fw = fresh weight (g), dw = dry weight (g).

Soil Organic Carbon (SOC) concentration was estimated using the conversion Equation (4) and SOM was estimated using Equation (5) (Wairiu & Lal, 2003).

$$SOC\left(\text{t C ha}^{-1}\right) = C(\%) \times \rho \times V \tag{4}$$

where: C% is the weight percentage of carbon in the soil depth, ρ is the bulk density of the soil in tm^{-3} and V is the volume (m^3) of soil per hectare.

$$SOM = SOC \times 1.78 \tag{5}$$

To estimate the amount of CO_2 equivalence (CO_2 Eq.) held in the soil from the atmosphere, the ratio of 12 g of C: 44 g of CO_2 was used, based on mass of carbon in the molar mass of CO_2 (Kum & Yinda, 2016).

Deterioration index (DI) was applied according to Equation (6) (Awotoye et al., 2011) to compute the rate of deterioration of the farmland soil properties compared to that of grazing and forest lands.

$$DI = \hat{X} - X_i/\hat{X} \tag{6}$$

where: $\hat{X}$ = mean value of soil property in grazing land or forest land, while X_i = mean value of soil property in farmland.

2.5. Statistical Analysis

Results from the laboratory were all keyed into Microsoft Excel 2016 and computed into secondary parameters (mean, standard deviation and standard error) to facilitate comparison between soil properties. These parameters were imported to SPSS 20 and R statistical packages to test for significant differences, compute boxplots and other inferential statistics. A one-way ANOVA was carried out to test the level of significance between soil properties of the various land uses. Significant differences were assessed at a p-value of 0.05.

3. Results

3.1. Land Use Map and Estimated Surface Areas for Smallholder Farms, Grazing, and Forest Lands

The land use map derived from the Landsat-4 data is shown on **Figure 2** and the land surface areas of smallholder farmlands, grazing lands, and forest lands are shown on **Table 1**. The land use types identified on **Figure 2** include; smallholder farm-lands, grazing land, forest (mountain forest, valley forest, dense forest, secondary forest), plantation, water bodies, and settlement. Grazing and forest lands each occupy more than a quarter (27.4% and 30.74% respectively) of the entire surface of the BH, while smallholder farms occupy just 4.6% (**Table 1**).

3.2. Soil Properties

The results of soil properties planned in this study are shown on **Table 2** and **Table 3**.

Soil Moisture, Bulk Density, Texture, and pH

Analysis of particle sizes from the laboratory revealed variation in soil texture of the land use types. The soil textures were sandy loam and sandy silt loam (**Table 2**). Calculations of soil bulk densities revealed slight variations in mean bulk densities of the land use types. Bulk density values ranged from 0.95 ± 0.04 (forest) to 1.09 ± 0.02 g/cm^3 (farms) with a significant difference between them ($F = 4.344$, $df = 2$, $p = 0.029$) (**Table 3**). Mean soil pH ranged from 4.87 ± 0.13 (farmland) to 5.25 ± 0.21 (grazing land) with no significant difference between them at 0.05 level (**Table 3**). Soil moisture content was lowest in smallholder farmlands (4.97% ± 0.35%) and highest in forest (7.34% ± 0.44%). The soil moisture content of these land uses differs significantly from each other at 0.01 level ($F = 9.108$, $df = 2$, $p = 0.002$).

SOC, Total Nitrogen (TN), and Available Phosphorus (Av.P)

Calculating the mean SOC (%) values from the three land uses revealed highest and lowest mean SOC (%) values in forest land (6.03% ± 0.81%) and smallholder farmland (4.07 ± 0.29) respectively (**Table 3**). The mean SOC values significantly differed from each other (F = 9.754, df = 2, p = 0.001). SOC values were generally high but factors TN and Av.P are generally low according FAO 2006 guide for integrated nutrient management with significantly differences recorded between them at α = 0.05 (Table 3). Table 3 also shows the index of deterioration of the soil properties under smallholder farmland use from forest and grazing lands. The deterioration indices were highest for N, SOC and moisture content. Available P, bulk density, and pH showed negative deterioration indices.

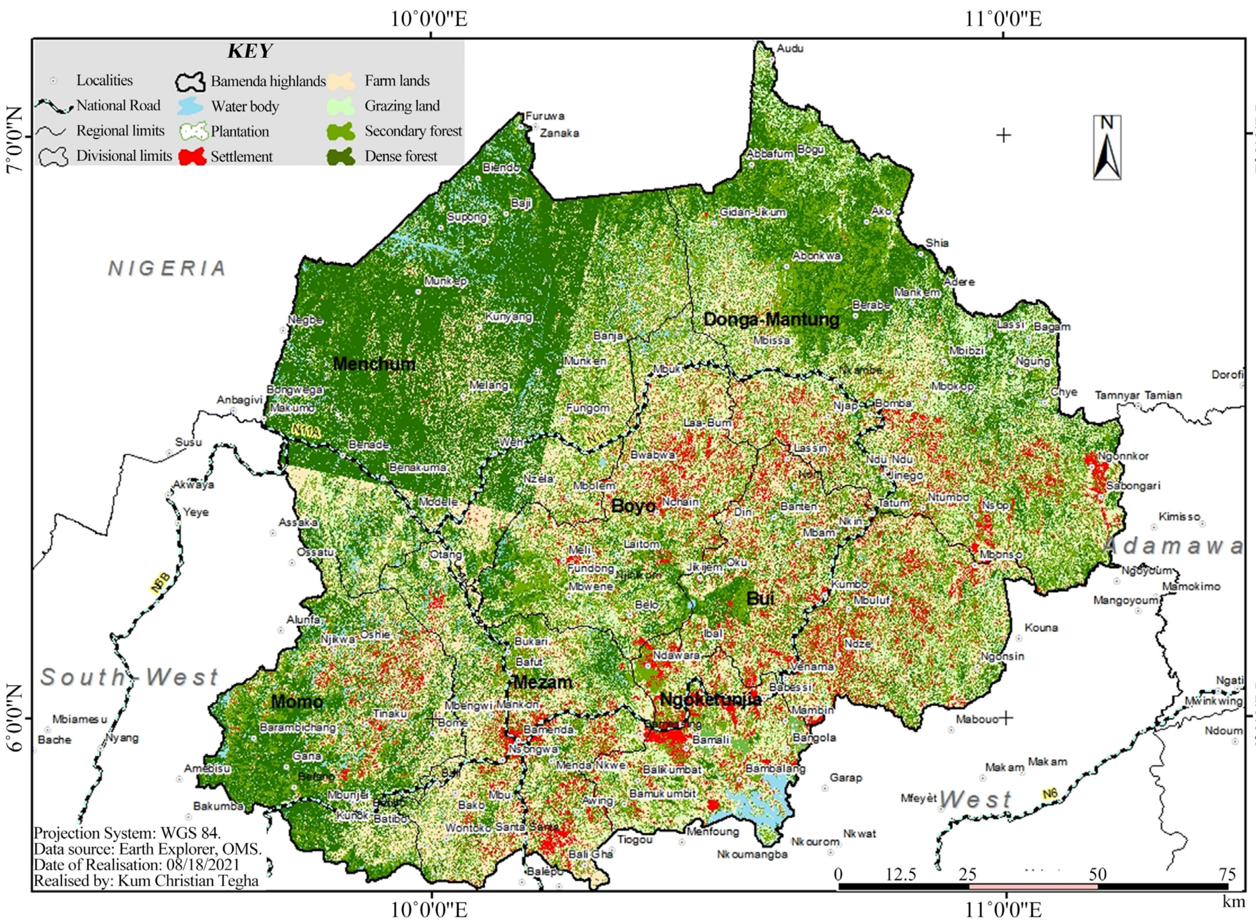

Figure 2. Land use map of the Bamenda Highlands, Cameroon.

Table 1. Estimated surface area of smallholder farmlands, grazing lands and forest lands in the Bamenda Highlands, Cameroon.

Grazing Lands		Smallholder Farmlands		Forest Lands	
Type of Grazing Land	Surface area (ha)	Types of smallholder farmland	Surface area (ha)	Types of Forest land	Surface area (ha)
Woody Grazing land	62,975.45	Pure Farmland	18.206.95	Evergreen Forest	156,434.35
Grazing land in cultivated lands	77,484.11	Farmland in forest	4,986.36	Valley Forest	322,039.39
Grazing land in forest	157,146.95	Farmland in savannah	43,807.15	Galerie Forest	10,017.45
Shrub Grazing land	179,033.13	Farmland in shrubs	13,719.79	Secondary Forest	45,886.45
Total	**476,677.51**	**Total**	**80,720.24**		**534,893.50**

Table 2. Mean sand, silt, and clay of the three land use systems.

Land use Type	Sand (%)	Silt (%)	Clay (%)	Textural Class
Smallholder farmlands	51.30 ± 2.52	35.27 ± 5.44	13.43 ± 1.34	Sandy Loam
Grazing land	40.79 ± 4.07	44.85 ± 3.80	14.36 ± 0.86	Sandy Silt Loam
Forest	44.49 ± 5.80	40.08 ± 5.35	15.43 ± 0.81	Sandy Silt loam
Total	45.53 ± 2.66	40.07 ± .74	14.40 ± 0.60	Sandy Silt Loam

Table 3. Mean soil properties (physical and chemical) and deterioration indices.

Land Use	MC (%)	BD (g/cm^3)	SOC (%)	Total N(g/kg)	Av. P (mg/kg)	pH (KCl)
Smallholder Farmlands	$4.97 \pm 0.35_{a,b}$	$1.09 \pm 0.02_b$	$4.07 \pm 0.29_a$	$2.33 \pm 0.17_b$	$19.70 \pm 1.94_b$	4.87 ± 0.13
Grazing land	$7.07 \pm 0.49_a$	0.98 ± 0.04	$5.52 \pm 0.37_a$	3.01 ± 0.32	$17.38 \pm 1.00_b$	5.25 ± 0.21
Forest	$7.34 \pm 0.44_b$	$0.95 \pm 0.04_b$	$6.03 \pm 0.81_a$	$3.49 \pm 0.24_b$	$15.52 \pm 1.87_b$	5.12 ± 0.15
Mean ± SE	6.46 ± 0.33	1.01 ± .02	5.21 ± 0.26	487.35 ± 34.77	16.87 ± 1.07	4.61 ± 0.09
			Soil Deterioration Indices			
Farmlands (from forest)	32.29	−14.74	32.50	33.24	−45.71	−2.18
Farmlands (from Grazing land)	29.70	−11.22	24.27	22.59	−13.35	−2.63

Values with the same letter within a column are not significantly different from each other at 0.05 level.

Relationship between Soil Properties

Results of the relationship between soil properties are shown on Table 4. The results reveal a significant positive correlation between SOC and TN, and SOC and moisture content. Meanwhile significant negative correlations were revealed between SOC and bulk density, SOC and Av.P, TN and bulk density, and nitrogen and phosphorus (Table 4).

Soil Organic Carbon Stocks

The mean SOC density in tC/ha ranged from 132.91 ± 9.48 for smallholder farmland-use to 170.37 ± 9.77 for forest land-use (Table 5). Estimated amounts of CO_2 equivalence from the SOC density values in each land-use type revealed highest mean value of 624.68 ± 35.80 t/ha of CO_2 equivalence for forest and lowest mean value of 487.35 ± 34.77 t/ha of CO_2 equivalence for smallholder farms (Table 5). Mean average soil organic matter (SOM) in t/ha for the 0 - 30 cm depth for the land-use systems ranged from 236.59 ± 16.88 t/ha in smallholder farmland-use to 298.97 ± 18.09 t/ha in forest land use (Figure 3).

Total organic carbon (TOC) stocks in mega tonnes (Mt) for 30 cm depth gave a maximum 91.13 Mt for forest and a minimum of 10.73 Mt for smallholder farms giving a total for the three land uses of 179.41 Mt (Table 5). Comparison of TOC stock (Mt) values for the three land uses using one way ANOVA test, revealed that these TOC stocks values differ significantly from each other at $\alpha = 0.05$ ($F = 8.03$, df = 2, $p = 0.015$) (Table 5).

Table 4. Pearson's Correlations between soil properties.

	SOC (%)	Bulk D (g/cm³)	Total N (g/kg)	Av. P (mg/kg)	pH (KCl)	Moisture (%)
SOC (%)	1					
Bulk D (g/cm³)	−0.559**	1				
Total N (g/kg)	0.920**	−0.645**	1			
Av. P (mg/kg)	−0.672**	0.396 ns	−0.623**	1		
pH (KCl)	0.119 ns	0.154 ns	0.033 ns	−0.158 ns	1	
Moisture (%)	0.521*	−0.387 ns	0.427 ns	−0.425 ns	0.046 ns	1

**Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed) ns Correlation is not significant at the 0.05 level (2-tailed).

Table 5. Comparison of SOC Stocks (within 30 cm depth) in the three LUS of the BH.

Land Use	*Estimated surface area (ha)*	*SOC (tC/ha)*	*CO_2 Eq. of SOC (t/ha)*	*TOC-Stocks (Mt)*	*CO_2 Eq. of TOC (Mt)*
Smallholder Farmlands	80,720.24	132.91 ± 9.48*	487.35 ± 34.77*	10.73*	39.34
Grazing Lands	476,677.51	162.68 ± 11.98*	596.48 ± 36.72*	77.55*	285.25
Forest lands	534,893.50	170.37 ± 9.77*	624.68 ± 35.80*	91.13*	334.14
Total/Mean	**1,092,291.25**	**155.32**	**569.49**	**179.41**	**659.73**

* The mean values differ significantly at 0.05 level.

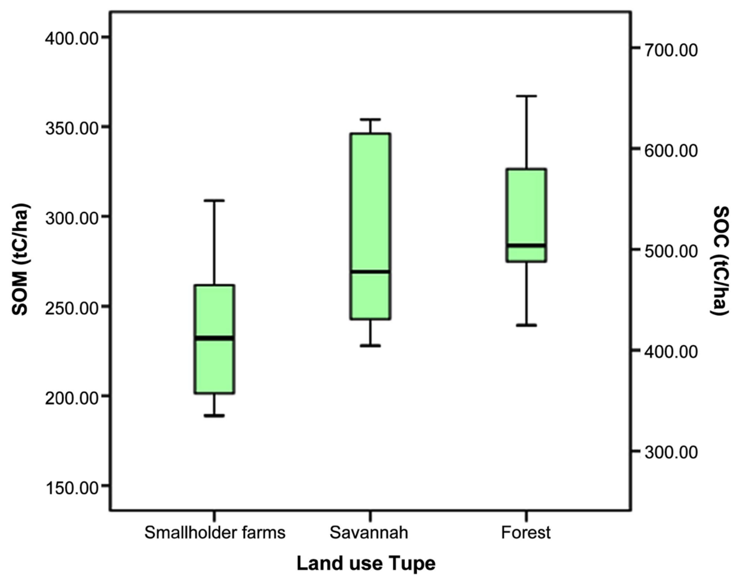

Figure 3. Box plot showing the SOM values in t/ha derived from SOC (tC/ha).

4. Discussions

4.1. Land Use Map and Estimated Surface Areas for Smallholder Farms, Savannah and Forest

The three land uses identified in this study including forest (natural or afforested), grazing land, and smallholder farmlands agrees with those identified by Tellen and Yerima (2018) in some selected sites of the BH. The forest land here is comprised of native trees and shrubs while the grazing lands are made of short grasses. Tellen and Yerima, 2018, and Azinwi et al., 2018 both described the vegetation of the BH as savannah zone dominated by short grasses and deciduous shrubs. This description is proven right by the results on **Table 1** and **Figure 2** which shows dominance in forest and savannah land area from other land uses. The area of smallholder farms is just about 5% of the total surface area of the BH, but the effects of the tillage practices on this area should not be minimized. Results from census studies of 2005 and 2015 shows an increase in population density of 100 persons/km^2 to 114 persons/km^2 in just 10 years. This increase in population will only result to more increase in smallholder farmlands at the expense of grazing and forest lands.

4.2. Soil Properties

Soil Moisture, Bulk Density, Texture, and pH

Results on **Table 2** indicate that sand is the primary soil particle among the three land uses in the BH, and the lowest sand content of 40.79 ± 4.07 occurred in the grazing LU. This could be due to different effects of soil erosion control in each of the LUS. The conversion of forest/grazing land into farmland 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 Kum and Yinda (2016) who also recorded different soil texture types for different land uses.

The results revealed higher BD in smallholder farms > Grazing land > forest with significant differences between BDs of farmlands and forest. This is in accord with the works of Sahani and Jiao et al. (2020), who also recorded higher BD in arable lands. The higher BD in smallholder farms could result from the combined influence of the ploughing in tillage layer, roots distribution, repeated sowing and harvesting, and human activities on the farm. These factors may lead to soil compaction resulting to higher BD.

In this study, variation in soil moisture content occurred among the three land uses, the lower moisture content observed in farmlands was likely related to the complete tillage ridge formation with no surface cover and irrigation. This leads to easy evaporation of soil moisture. Moisture content between forest and grazing land LUS had no significant difference between them but the higher MC in forest could be due to more surface cover by leave litter (Jiao et al., 2020).

The pH (4.87 to 5.25) across the three land use types was homogenous and showed moderate acidity in accordance with the Kum and Yinda, (2016) who also revealed homogenous and moderate acidity pH values in different land use type at the southern parts of the Mount Cameroon National Park (MCNP). The lower pH value in farmland can be attributed to the use of chemicals by some smallholder farmers in the BH to preserve soil fertility.

SOC, Total Nitrogen (TN), and Available Phosphorus (Av.P)

The SOC that ranged from 4.07% to 6.03% are slightly more than the results of Tellen and Yerima (2018), which stood at 2.77% to 4.73% SOC on the North

West Region of Cameroon. The higher values in this study are probably due to fact that Tellen and Yerima (2018) cover only two of the 7 microclimatic zones of the BH during their sample collection. Also, some of the smallholder farms in this study had gone through a fallow period of 2 - 3 years before recultivation unlike the continuous cultivation farms in Tellen and Yerima (2018). Soil fertility values (SOC and total N) were highest in forest, grazing land, and farmland in that order with significant differences recorded between the values at $p < 0.05$ (**Table 3**). Higher SOC and TN in forest are probably due to the high accumulation and decay of leaf litter and roots within the forest than grazing land and farmlands in accordance with Tellen & Yerima, (2018) and Kum and Yinda (2016). Lower SOC and TN in the farmlands could be due to soil exposure and lack of understory vegetation which leaves the soil vulnerable to erosion that washes away topsoil nutrients (Boley et al., 2009). Phosphorus values from the soils of these land use types were slightly above the critical value for phosphorus in soils (around 15 mg/kg for Bray-II), indicating the good soil quality of the zone and making the area suitable for agriculture. The significantly higher mean Av.P in farm lands use than forest and grazing land uses are probably due to application of fertilizers. This agrees with the results of Shrestha et al. (2007) who attributed higher values of Phosphorus in Bari soils to application of fertilizers.

The results of soil deterioration index revealed that MC, SOC, and TN of farmland soils are the most deteriorated properties from forest and grazing lands. The higher BD value in farmlands signifies deterioration. Higher Av.P and pH values in farmlands signify soil improvement probably resulting from farm management practices.

Relationship between Soil Properties

Significant correlations ($p < 0.05$) were recorded between soil physicochemical properties (**Table 4**). SOC correlated positively with the total nitrogen (r = 0.920), and moisture content (r = 0.521) indicating that an increase in the SOC also increases soil's total nitrogen and moisture. Moisture content is important for the determination of mineralization rates and conservation of SOM in the soils. Nitrogen is a macro plant nutrient whose availability in soil increases with increase SOC (Okeke, 2014). SOC negatively correlated with BD, Av.P suggesting that an increase in SOC decreases BD and Av.P and vice versa. This result is in agreement with Jiao et al. (2020) who also found negative correlations between SOC and BD. Land use practices and inputs can change the dynamic of soil properties yielding some of these negative relationships. Results on **Table 4** clearly show that there exists a relationship between the soil physicochemical properties which affects the availability of nutrients.

Soil Organic Carbon Stocks

Soil carbon density which is key to total SOC stock estimation ranged from 132.91 ± 9.48 (farmlands) to 170.37 ± 9.77 tC/ha (forest). These results were found to be higher than those of Nasi et al. (2009) from various ecosystems in the Congo basin ranging 35 to 82 t/ha. This higher SOC stock could be the result of humic ferralsols, rich in SOC and suitable for agriculture. LU can change the function of soils from a carbon source to a carbon sink and vice versa (Zhang & Shangguan, 2016). Results of this study found that SOC density, SOM, and TOC stock were the highest in forest land, possibly due to input of litter on the surface soil. While the smallholder farmland with little or no litter, frequent disturbance and strong soil respiration in the surface, may have enhanced SOC consumption in the top 30 cm soil rendering farmland with lowest SOC values. This is in accordance with Jiao et al. (2020) who also found highest SOC content and stocks in forest land and least in arable land. The significant differences in TOC and SOM observed between the three LUSs are in response to the changes in land use/management practices. Land conversion from forest/grazing lands to smallholder farmlands increases soil mineralisation resulting to SOC decline and, thus, soil degradation (Kum & Yinda 2016; Lal, 2004). Soils under grazing land follow those under forest in SOC stocks as expected because high plant species diversity in grazing land is known to enhance SOC (FAO, 2001) due to diversity in residue that decays directly into the soil.

5. Conclusion

Soil MC, BD, and texture play an important role in SOC formation and transformation during land-use and/or land-cover changes. This study revealed robust changes in these soil physical properties and SOC, and TN among the smallholder farmlands, grazing and forest lands. The potential ability to sequester SOC was in the order: forest lands > grazing lands > smallholder farmlands. This trend reflects the current management practice. Most forest lands are either protected or inaccessible with little human activities resulting in much litter accumulation and degradation to SOC. Grazing lands are affected by seasonal grazing activities leading to a reduction in litter accumulation. Smallholder farmlands are completely exposed to air for easy conversion of SOC to CO_2. Smallholder farmlands are therefore detrimental to SOC sequestration and possibly contribute significant amounts to rising levels of atmospheric CO_2. The CO_2 equivalence held by soils of these land-use types follows the same order as SOC, with forest lands having the highest value and smallholder farmlands the least. The significant differences in TOC-stocks between forest/grazing lands and smallholder farmlands prove that forest/grazing-land conservation is important and needed, if the fight against climate change is to be confronted. This therefore gives additional impetus for the protection of forest lands in the BH. Therefore, the long-term conventional cultivation of smallholder farmlands is not favorable to SOC management. More attention should be tailored to improving the soil quality in smallholder farmlands.

This research was aimed at setting a baseline for total SOC stocks in the BH, which is necessary for future SOC stock modelling and estimation of carbon sequestration potential of various land use systems in the area. In Cameroon, a national SOC database is not available and this could hinder the country's access to funds from the Clean Development Mechanism (CDM) as proposed under article 12 of the Kyoto Protocol of the UNFCCC. This local level total SOC stocks estimation should serve as a starting point for large scale modelling/estimations of past and future SOC stocks and provide some accuracy for a national SOC data.

Authors' Contributions

KCT literature review, field survey, data collection and analysis and manuscript preparation and submissions. TAS overall management of the field survey, technical support and reviewing the manuscript, NM/TC technical support and reviewing the manuscript. All authors read and approved the final manuscript.

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Declaration

This research article is written by the authors whose names have been appropriately indicated.

Ethics Approval and Consent to Participate

The authors hereby declare that; this manuscript has not been published or considered for publication elsewhere.

Conflicts of Interest

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

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