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Soil Organic Carbon Stock Variation under Different Soil Types and Land Uses in the Sub-Humid Noun Plain, Western Cameroon

Frank Abigail Sobze Kenfack[1*], Georges Kogge Kome[2], Achille Bienvenue Ibrahim[1], Viviane Pauline Mandah[3,4], Dieudonne Bitondo[1]

[1]Department of Soil Science, Faculty of Agronomy and Agricultural Sciences (FASA), University of Dschang, Dschang, Cameroon
[2]Department of Land Surveying, National Advanced School of Public Works, Yaoundé, Cameroon
[3]International Institute of Tropical Agriculture Cameroon, Eco-Regional Center HFS, Yaoundé, Cameroon
[4]Department of Earth Science, Faculty of Science, University of Dschang, Dschang, Cameroon
Email: *kenfackfrank77@gmail.com

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Abstract

This study was conducted to assess the current stock of soil organic carbon under different agricultural land uses, soil types and soil depths in the Noun plain in western Cameroon. Three sites were selected for the study, namely Mangoum, Makeka and Fossang, representative of the three dominant soil types of the noun plain (Andosols, Acrisols and Ferralsols). Three land uses were selected per site including natural vegetation, agroforest and crop field. Soil was sampled at three depths; 0 - 20 cm, 20 - 40 cm, and 40 - 60 cm. Analysis of variance showed that soil type did not significantly influence carbon storage, but rather land uses and soil depth. SOCS decreased significantly with depth in all the sites, with an average stock of 66.3 ± 15.8 tC/ha at 0 - 20 cm, compared to an average stock of 33.3 ± 7.4 tC/ha at 40 - 60 cm. SOCS was significantly highest in the natural formation with 57.2 ± 19.7 tC/ha, and lowest in cultivated fields, at 37.7 ± 10.6 tC/ha. Andosols, with their high content of coarse fragments, stored less organic carbon than Ferralsols and Acrisols.

Keywords

Carbon Stocks, Soil Type, Soil Depth, Agricultural Land Use, Noun Plain

1. Introduction

Sub-Saharan Africa is currently witnessing strong demographic growth, with its population expected to double by 2050 [1]. The rapid increase in population is generally accompanied by an increase in the demand for arable land, leading to an extensification of agriculture, which is the main economic activity for most inhabitants of developing countries [2]. According to Kögel-Knabner and Amelung [3], global population growth enhances land conversion, with accompanying negative consequences such as soil degradation. Don *et al.* [4] reported that the strong demographic pressure is the main driving force behind the expansion of large areas and agricultural extensification, with the main consequences being deforestation and soil fertility decline. In this respect, Kohio *et al.* [5] stated that soils subjected to such anthropogenic pressure become very sensitive and their agricultural performance will decline considerably. According to Tellen and Yerima [6], this decline often happens very rapidly in tropical landscapes; often with a change in the functioning of the entire agroecosystem [7]. These various changes inevitably lead to the depletion of the soil organic carbon stock (SOCS) and a drop in productivity [8].

Any substance, element or material produced by living organisms that returns to the soil and undergoes biotransformation is considered to be soil organic carbon (SOC) [9] [10]. Despite its low proportion in the soil, it is an essential parameter, which has been the subject of several high-quality studies as reported by Fujisaki [11]. Indeed, SOC plays a fundamental role in maintaining soil fertility in tropical and subtropical environments, thereby enhancing soil health and agricultural productivity [12] [13] [14]. Likewise, Atchada *et al.* [15] argue that this parameter has an impact on the sustainability of agro-ecosystems and environmental protection. Soil organic carbon stocks are often lowest where soil degradation is high, and where soil/water losses are considerable. This is the same where productivity is low and ecosystem services are declining [16] [17]. In a nutshell, SOC is a major determinant of ecosystem functioning [18] [19].

The storage of organic carbon (OC) in soils is controlled by physical, chemical, biological and environmental factors [20] [21]. According to Kögel-Knabner and Amelung [3], different types of soil groups store different amounts of SOC. In the same light, several studies carried out on a wide variety of climates illustrate the effect of soil type on soil organic carbon storage. Examples include the works conducted in the Amazon rainforests on three soil types [22], in south-east Germany on eight soil types [23], in Brazil on four soil types [12], in southern Benin on three soil types [24], in western Italy on seven soil types [25] and in the "Mbo" plain of western Cameroon on five soil types [26]. These research works amongst others suggest that the variability in carbon stock with respect to soil type can be explained by the composition of soil minerals, the degree of weathering and the evolution of the soil profile.

[27] illustrates a significant relationship between soil particles (<2 mm) and SOCS. Other studies have focused exclusively on the stabilisation of organic carbon in soils by fine particles [12] [28]. According to Atchada *et al.* [15], an increase in fine particles (silt + clay) leads to an increase in soil organic carbon storage. More recently, some scientists have been examining the effect of coarse fragments (>2 mm) on soil organic carbon storage potential. Many studies have

shown that these stocks are highly dependent on the percentage of the coarse fraction [29] [30] [31].

The noun plain in the western highlands is witnessing a decline in SOC stocks caused by land degradation, the extent of which has not yet been well assessed [32] [33]. It is estimated that 86% of the soil in west Cameroon is already used for agricultural purposes, compared with 25% in the rest of the country [34]. It has also been reported that overexploitation of agricultural land is causing a decline in soil productivity at a rate of 25% [35]. An analysis of crop production data over the last three decades shows that the noun plain has seen a 20% drop in agricultural yields [36]. To date, no studies have been carried out in the Noun agricultural plain to assess the impact of soil types and land use change on the potential for storing OC in the soil. Therefore, the main objective of this study was to evaluate the relationship between SOCS, soil type and land use in the sub-humid Noun plain in western Cameroon. An understanding of these relationships will be helpful in identifying different land uses that can support agricultural development and sustainability in the locality.

2. Materials and Methods

2.1. Location and Description of Study Area

The Noun plain, in the western region of Cameroon, lies between latitudes 5˚10' to 5˚40' N and longitudes 10˚20' to 10˚50' E (**Figure 1**). It covers an area of approximately 2554 km^2 with a strip of 10 - 20 km on either side of the River Noun, with an eastward extension towards the Bamouns [37].

The plain belongs to the tropical Sudano-Guinean climatic region of the "mountain monsoon" type, but is slightly modified by the double orographic protection of its plateau [38]; it receives an average annual rainfall of 1983 mm characterised by a unimodal pattern, with a peak in September. The topography of the region varies considerably, ranging from depressions less than 900 m above sea level to high mountains at 2250 m above sea level. Two geological formations make up this area: the Precambrian basement "granite-gneissic", which is the bedrock, made up of metamorphic rocks and plutonic magmatic rocks, and the recent volcanic formations, made up of basaltic plateau and pyroclastic deposits (ash, lapillis, volcanic bombs) [38].

2.2. Land-Use Characteristics

Multiple field trips carried out between 2019 and 2022 revealed that the Noun plain is characterised by three main categories of land uses namely; natural formations, crop fields and agroforests. Aerial photographs and satellite images of the study area were used to identify and classify the most common land uses currently found in the plain. The different land use types are briefly described below.

The natural formations are made up of remnants of deciduous seed forests that remain on flooded plains, savannahs that are mainly found at the top of

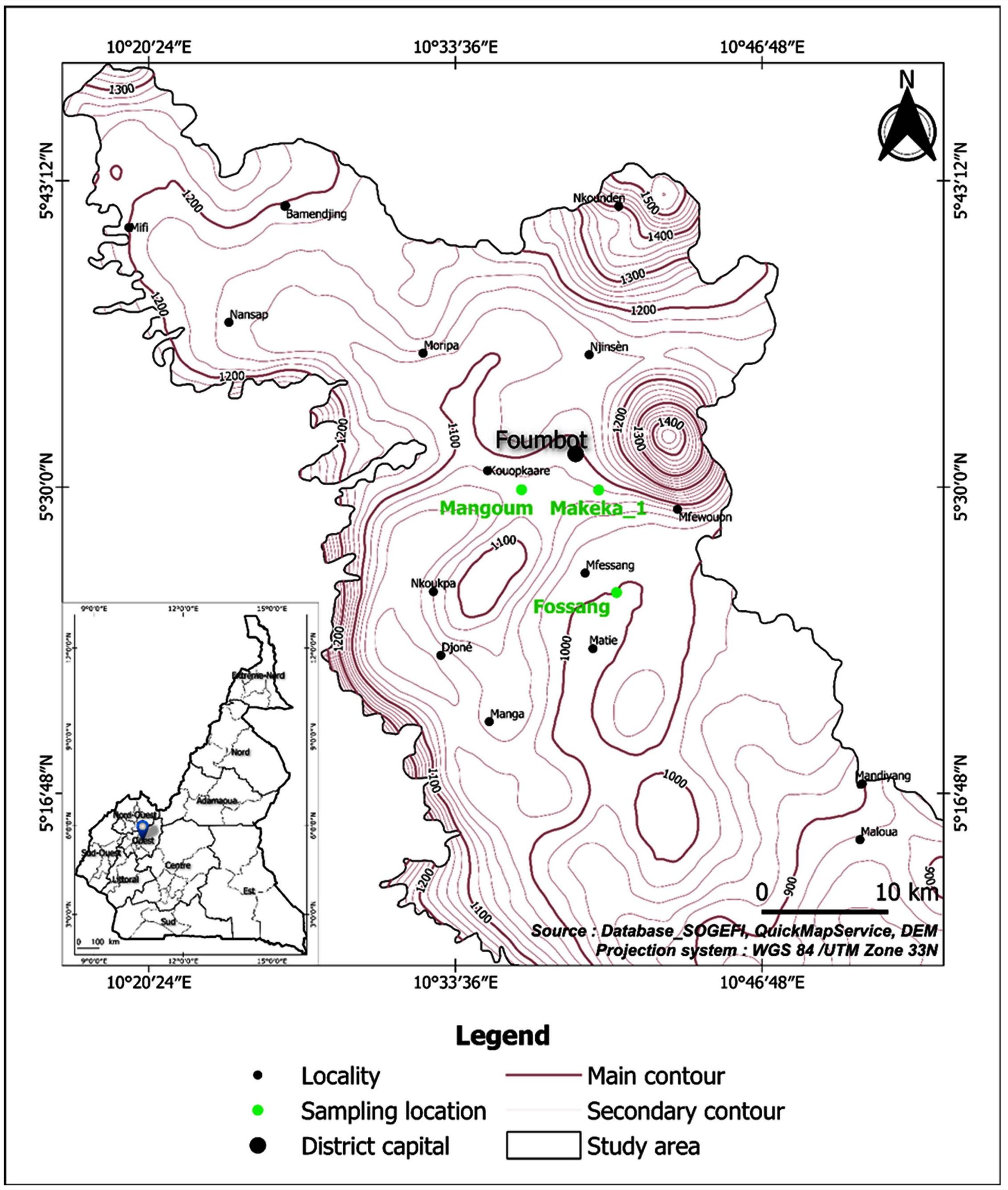

Figure 1. Study area and sampling stations.

mountains, at high altitudes and in very hilly areas, and mixed woody plant formations (fallow land that is more than twenty years old). These natural formations are often reserved for cattle breeders in the Noun plain. The dominant species in this group include *Ceiba pentandra, Milicia excelsa, Khaya anthotheca, Lovoa trichilioides, Mitragyna ciliate* and others. This type of land use covers an average of 172˚177.57 ha (71.01%) of the total area of the landscape.

Agroforests are made up of perennial crops such as coffee (*Coffea arabica*), cocoa (*Theobroma cacao*), orchards and palm trees (*Raphia farinifera*), although these are increasingly in decline. In the 1930s and 1940s, coffee was the main cash crop [39], grown on two thirds of the plain. This type of land use covers an average of 24˚113.88 ha (9.95%) of the total area of the landscape. The change in the land use system is clearly visible, with a reduction in coffee-growing areas in favour of annual crops, resulting in a management style characterised by diversification [40].

Crop fields in the Noun plain are characterised by a crop rotation of two annual crop cycles practised in almost the entire study area throughout the year. A maize cycle from mid-March to mid-July and a bean cycle from mid-August to mid-December. This land use type covers around 43˚391.80 ha (17.90%) of the total area of the Noun plain, and includes areas used for rain-fed and irrigated farming, including rural farms. The main crops are cereals—mainly maize (*Zea mays*), pulses—mainly beans (*Phaseolus vulgaris*) and groundnuts (Arachis hypogaea) and oilseeds—mainly soybean (*Glycine max*). The use of chemical fertilizers is practically indispensable on the plains. However, some farmers combine it with animal droppings and manure. The land is usually prepared manually through conventional tillage and mechanically using various machines.

2.3. Sampling Sites

Three study sites were selected using a stratified random sampling technique. Each stratum represents a reference soil group. The representative study sites selected include the Mangoum series (Andosols), the Makeka 1 series (Ferralsols) and the Fossang series (Acrisols) (**Table 1**).

2.4. Soil Sampling

In the three sites, nine (09) soil profiles were dug and described following standard procedures [41]. A representative soil profile of dimensions 1.5 m × 1 m × 2 m was dug on each type of land use selected [42]. The Dutch knife and auger were used to collect soil samples at three depth intervals (0 - 20 cm; 20 - 40 cm; and 40 - 60 cm). Additionally, undisturbed soil samples were collected using stainless steel Kopecky rings for bulk density determination. A total of 27 soil samples were collected.

2.5. Laboratory Analysis

The soil samples were air-dried and sieved through a 2 mm sieve for routine laboratory analysis. Particle size distribution was determined by the hydrometer method; bulk density (BD) was measured by the core method; total porosity was

Table 1. Sampling sites and geographic location.

Site	Location	Geographic coordinates
1	Mangoum	Lat: 05˚29’53.1”N; Long: 10˚36’27.0”E
2	Makeka	Lat: 05˚29’52.2”N; Long: 10˚39’46.0”E
3	Fossang	Lat: 05˚25’27.4”N; Long: 10˚40’32.3”E

calculated using a mathematical relationship between bulk density and particle density (PD) (Porosity = (1 − BD/PD) × 100, where PD = 2.65). Organic carbon was determined using the Walkley and Black method. All parameters were determined according to [43]. The method used to calculate soil carbon stocks involves measuring the total organic carbon content at different soil depths and transforming these data, taking into account the soil bulk density and coarse element load. As a first step, we determined the organic carbon stock at each depth using the following formula:

$$\text{SOCS}\ \left(\text{t/ha}\right)=\text{soil depth}\times\text{BD}\times\text{Cconc.}\times\left(1-\text{gravel}\right) \quad (1)$$

These stock values were used to assess the variation in SOCS with depth.

Where,

SOCS = soil organic carbon stock for each profile representative of the type of land use and soil studied at a given point (expressed in tons C/ha);

Cconc. = soil organic carbon content;

Gravel = volume percentage of coarse fragments (>2 mm).

2.6. Data Analysis

Statistical analyses were performed using R software version 3.5.1 and Microsoft Excel software 2013 edition for Windows. Data obtained in the laboratory were subjected to an analysis of variance (ANOVA) using the General Linear Model procedure. Means were separated using the Student-Newman Keuls test, based on the calculation of the least significant difference (LSD) at the 5% probability threshold. To ensure that the results obtained follow a normal distribution law, the Shapiro-Wilks normality test was performed, drawing on the work of [44]. To appreciate the extent of variability of the soil organic carbon stocks, a coefficient of variation (CV) was calculated using the formula:

$$\text{CV}=\sigma/\overline{X}\times 100 \quad (2)$$

where, σ: Standard deviation; $\overline{X}$ = arithmetic mean. The CV (%) was assessed according to [45]. Based on this, CV values < 15% were considered as least variable; those with CV between 15 and 35% were grouped as moderately variable and those with CV values > 35% indicated high variability.

3. Results

3.1. Characteristics of Studied Parameters According to the Soil Type

3.1.1. Variation in Particle Size Distribution

Table 2 shows some physical parameters of the three groups of soils representative of the Noun agricultural plain. The texture of the Andosols is dominated by sand, with much higher proportions after the first 40 cm depth for all three profiles representative of this soil type. The average percentage of sand reaches 66.66% at depth (40 - 60 cm), resulting in a sandy-loam textural class for these leptic Andosols. The trend in fine elements (silt and clay) in this soil group shows a decreasing variation with depth in general, with lower proportions of silt reaching 13.5%, compared with 4% for clay content. In Acrisols and Ferralsols, the clay content varies from a minimum of 13.60% at a depth of 20 cm to a maximum of 59.6% at 60 cm, with the percentage increasing over the six profiles that characterise the two soil types. The texture of the Ferralsols is sandy-clay to silt-clay at the surface (0 - 20 cm), and clayey at the subsurface (40 - 60 cm). The texture class of the Acrisols is clayey from surface to subsurface. The sand content in the surface layer of the profile was higher than that at deeper layers in the Ferralsols, although in the Acrisols the trend was rather erratic. However, the proportion of fine elements increased with soil depth. Overall, significant differences were observed between each soil fraction (sand, silt, clay) on each soil type and between the different depth levels. Furthermore, Table 3 shows that in all three soil groups and as a function of depth, the degree of interdependence between sand and fine elements is close to 1 ($r = -0.999^{**}$, $p < 0.01$). However, the correlation between the different soil particles and the carbon stock was not significant.

Table 2. Mean of parameters studied as a function of soil type.

Soils types	Depth (cm)	RF (%)	BD ($Mg \cdot m^{-3}$)	Sand (%)	Silt (%)	Clay (%)	Clay + silt (%)	SOC (%)	SOCS (tC/ha)	Soil textural class#
Ferralsols	0 - 20	1.75	0.88	45.13	28.33	26.53	54.00	3.80	64.80	SCL
	20 - 40	2.11	0.91	34.00	26.17	39.83	66.00	2.50	45.60	CL
	40 - 60	1.09	0.90	27.50	23.43	49.10	72.53	1.70	30.60	C
Andosols	0 - 20	12.54	0.74	53.33	28.33	18.50	46.83	5.30	68.20	SL
	20 - 40	23.48	0.78	57.17	22.17	20.50	42.66	4.60	51.00	SCL
	40 - 60	22.56	0.80	66.66	18.00	15.17	33.33	2.40	28.30	SL
Acrisols	0 - 20	3.40	0.95	27.66	31.33	41.00	72.33	3.60	65.80	C
	20 - 40	1.65	0.99	27.33	25.50	47.16	72.67	2.40	47.60	C
	40 - 60	1.29	1.03	33.33	18.16	48.50	66.66	2.00	41.10	C

RF: rough fragment; SCL: sandy-clay loam; CL: clayey loam; C: clay; SL: sandy loam. #: [41].

Table 3. Spearman correlation matrix for linear relationships between selected soil parameters.

Variables	RF	Sand	Silt	Clay	Clay + silt	BD	SOCS
RF	1						
Sand	0.617**	1					
Silt	−0.235	−0.370*	1				
Clay	−0.585**	−0.943**	0.042	1			
Clay + silt	−0.620**	−0.999**	0.372*	0.943**	1		
BD	−0.554**	−0.569**	−0.149	0.677**	0.579**	1	
SOCS	−0.470**	−0.155	0.142	0.123	0.160	0.204	1

Coefficients at $p < 0.05$ are significantly correlated; *: $p \leq 0.05$; **: $p \leq 0.01$; RF: rough fragment.

3.1.2. Bulk Density

Average bulk density values vary from 0.74 Mg/m^3 to 0.8 Mg/m^3 in Andosols, from 0.88 Mg/m^3 to 0.91 Mg/m^3 in Ferralsols and from 0.95 Mg/m^3 to 1.03 Mg/m^3 in Acrisols. The distribution of bulk density in the different soil types is associated with different soil natures and compositions. There is a positive and non-significant correlation between bulk density and soil organic carbon stocks ($r = 0.204$, $p < 0.232$), indicating that bulk density values provide information on soil organic carbon stocks.

3.1.3. Soil Organic Carbon Content and Stock

The two parameters follow a paired variation as a function of soil depth and soil type. The average values for soil organic carbon content and stock are highest at the surface (0 - 20 cm) and lowest in the 40-60 cm layer. Andosols have the highest surface carbon stock (68.2 tC/ha) compared with Acrisols (65.8 tC/ha) and Ferralsols (64.8 tC/ha), and the lowest carbon stock in subsurface layers, which stands at 28.3 tC/ha compared with 30.6 tC/ha and 41.1 tC/ha for Ferralsols and Acrisols, respectively. All parameters considered in the study did not show any significant correlation with SOCS, except the coarse fragments.

3.2. Combined Effect of Soil Type and Land Use on Organic Carbon Stocks

Soil type and land use are controlling factors of soil organic carbon stocks. Table 4 presents the results of the analysis of variance of the interactive effect of soil type and land use on SOCS. These results show that the combined effect of land

Table 4. Effects of soil type, land uses and depth on SOCS.

Variables	Mean (t·ha^{-1})	Standard error	CV (%)	DF	Pr (>F)
Soil type				2	0.45
Ferralsols	46.9 a	19.4	38.9		
Andosols	52.0 a	20.7	39.3		
Acrisols	51.5 a	17.4	33.8		
ST*LU				4	0.177
Land uses				2	0.0045
Natural formation	58.9 a	19.6	33.3		
Agroforest	49.6 b	18.6	37.5		
Crop field	42.0b	15.2	36.2		
LU*D				6	0.40
Depth				3	0.00018
0 - 20 cm	66.3 a	15.8	23.8		
20 - 40 cm	48.1 b	10.9	22.7		
40 - 60 cm	33.3 c	7.4	22.2		

DF: Degree of freedom; CV: coefficient of variation; ST: soil type; LU: land uses; D: depth.

use and soil type did not reveal any significant difference ($p < 0.177$). Comparison of soil type mean values shows that the highest organic carbon stock was obtained in Andosols (52.0 tC/ha) and the lowest in Ferralsols (46.9 tC/ha). However, this difference was not significant. For the different land use types, the separation of the means indicates that the SOCS is significantly higher in natural formations (58.9 tC/ha) compared to agroforests (49.6 tC/ha) and crop fields (42.0 tC/ha). Figure 2 and Figure 3 show the variations of SOCS with soil type and land use, respectively.

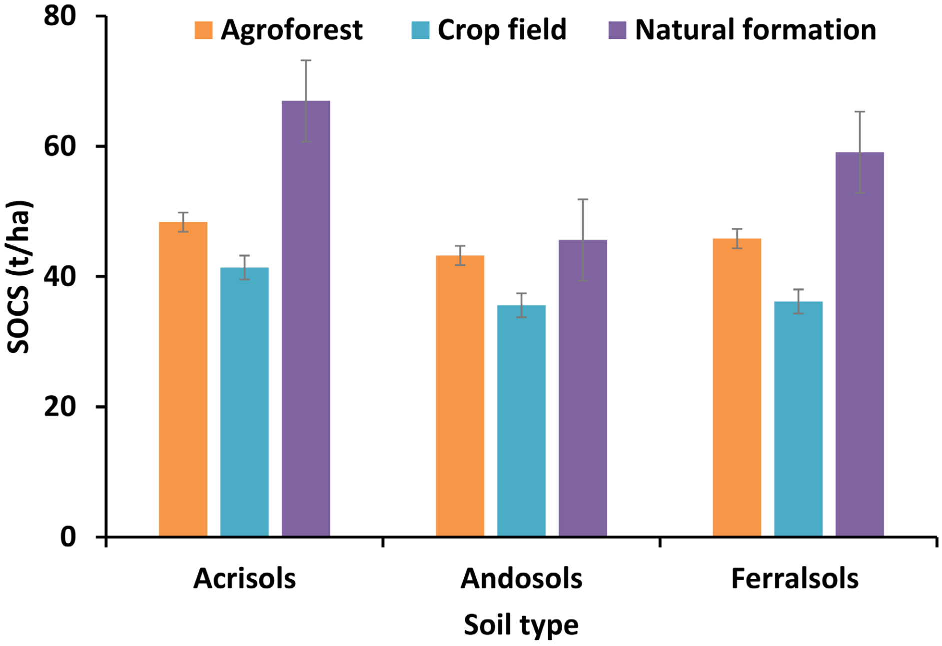

Figure 2. Variation of soil organic carbon stock (t/ha) across different soil types.

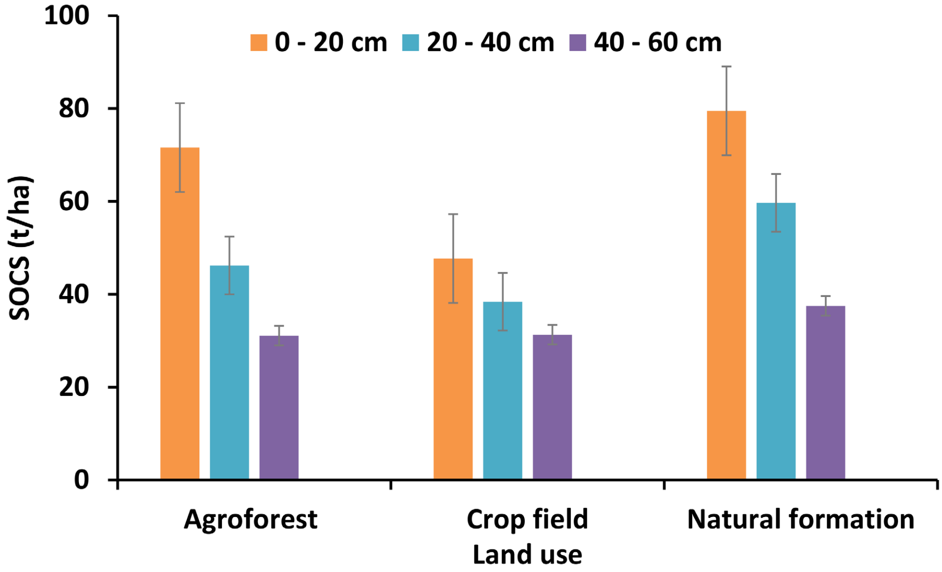

Figure 3. Variation of soil organic carbon stock (t/ha) across different land uses.

3.3. Combined Effect of Land Use and Soil Depth on Organic Carbon Stocks

SOCS decreased with depth in all land use types (**Table 4**). The results show that the organic carbon stock decreased with depth to 33.3 tC/ha in the 40 - 60 cm interval. Analysis of variance revealed a significant difference in SOCS between depths on the one hand ($p < 0.00018$) and between land-use types on the other hand ($p < 0.0045$). However, the interactive effect of land use and soil depth on SOC stock was not significant ($p < 0.4072$). At all three depths studied, SOCS of natural formations was higher than that of agroforests and cultivated fields.

3.4. Combined Effect of Coarse Fragments and Soil Type on Organic Carbon Stock

Variations in soil parameters, such as the OC stock in an environment, are influenced by the distribution and interaction of soil-forming factors such as climate, organisms, topography, parent materials and time. The degree of stabilization of SOC also depends on uncontrollable factors, including coarse fragments. The three groups of soils studied are characterized by varying proportions of coarse fragments. The results show that the content of mineral rejections > 2 mm, which is used to calculate the SOCS of fine soil, is higher in Andosols (51.73%). On the other hand, in Acrisols and Ferralsols, it is relatively low (<4%) throughout the Noun plain. On all the data, we obtained a negative and significant correlation at the 0.01% threshold between coarse fragments and the other parameters of the study, namely: fine elements ($r = -0.620$), apparent density ($r = -0.554$) and organic carbon stock ($r = -0.470$). **Figure 4** shows the relationship between soil organic carbon stock and coarse elements for the three soil types studied. We note from the different coefficients of determination that the correlation is strong and significant in Andosols ($R^2 > 0.5$; $r = -0.79$; $p = 0.0022$), but weak and non-significant in Ferralsols and Acrisols ($R^2 < 0.5$).

4. Discussion

4.1. Dynamics of SOC Stocks as a Function of Soil Type

There was no significant difference between SOCS for the three soil types. This result is similar to the findings of Canedoli *et al.* [25] in western Italy, where no significant differences were observed between the five soil types studied (Cambisols, Leptosols, Podzols, Regosols and Umbrisols) in the Gran Paradiso National Park. However, a study conducted on three soil types (limestone soil, rice paddy soil and yellow soil) in karst regions illustrates the influence of soil type in the variation of SOCS [46]. It was reported that, this difference stems from the fact that the soil formation conditions and processes of the three soil types in the study area were clearly different. A study carried out in southern Benin in a subequatorial climate by Kooke *et al.* [24] corroborates the above, but of the three soil types studied, hydromorphic soils store significantly more carbon than ferralitic soils and ferruginous soils, *i.e.* 14.14 tC/ha, 7.45 tC/ha and 5.28 tC/ha, respectively.

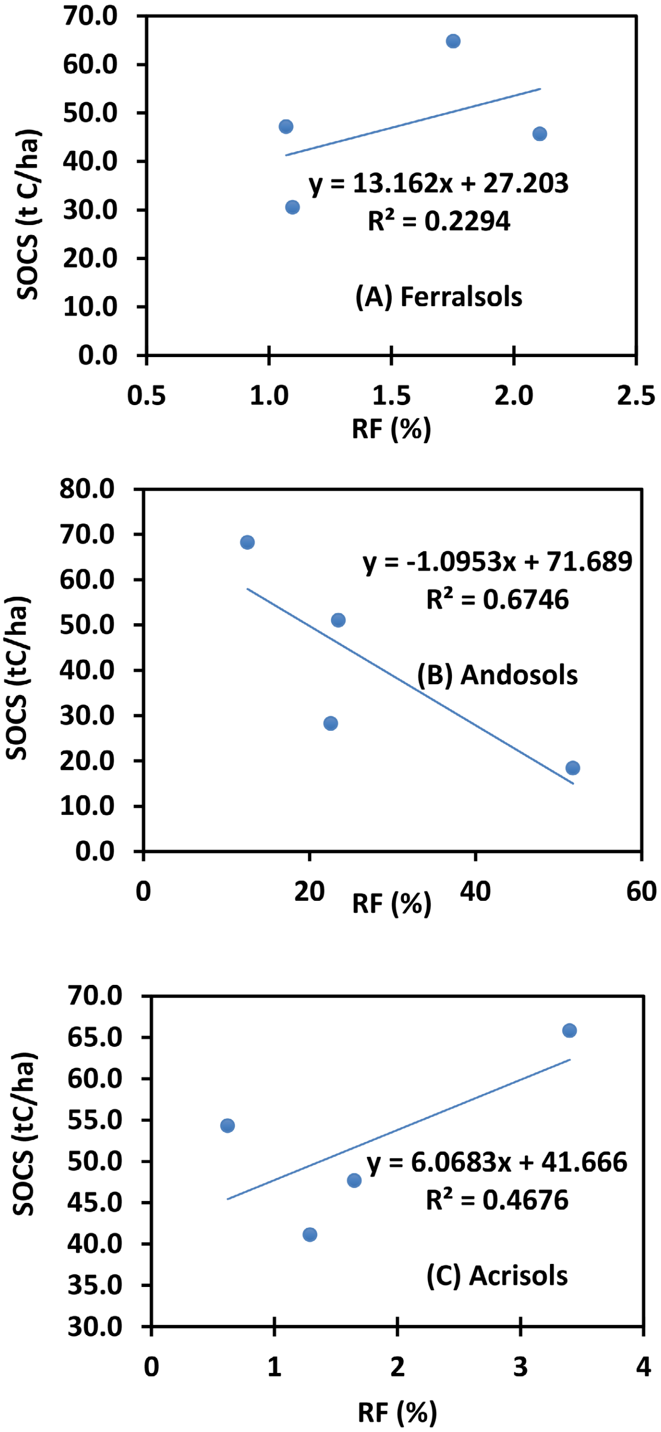

Figure 4. Relationship between soil organic carbon stock and rough fragments in three soil types. SOCS: soil organic carbon stock; RF: rough fragment.

The results illustrate a high variability (CV > 30%) of SOCS according to each soil type in the Noun plain. This result suggests that there is considerable heterogeneity within each soil type, probably due to their inherent potential. For Kögel-Knabner and Amelung [3], these multiple differences are underpinned by factors such as the formation of reactive mineral surfaces and soil aggregation. These results are in agreement with those of Munoz-Rojas *et al.* [47] and Chevallier *et al.* [48] carried out in southern Spain and Costa Rica, respectively, where the coefficients of variation are well above 30% within the different soil types studied.

Acrisols and Ferralsols are both formed on granito-gneiss with higher levels of fine elements than Andosols formed on very recent pyroclastic deposits and rich in coarse fragments. In fact, young soils formed on recent volcanic deposits on the plain have low SOCS due to the low quantities of secondary minerals they contain, which gives them a low capacity for adsorption and stabilisation of organic matter. This finding is essentially similar to that made by Munoz-Rojas *et al.* [47] with coarse-textured arenosols, which showed very low carbon stocks compared to what should be. The same observation was made on three types of soil in the Amazon rainforest, where soils with a high sand content had significantly low SOCS [22]. It should be noted that Andosols developed on tuffs and volcanic ash store more soil organic carbon because they are rich in allophanes, which contribute to the stabilisation of organic matter, than Andosols developed on recent pyroclastic deposits [3] [48]. According to Abera and Wolde-Meskel [49], the presence of factors such as high fractions of micro-aggregates can provide physical protection for soil organic matter and thus contribute to the slow rate of organic carbon loss.

4.2. Dynamics of SOCS as a Function of Coarse Fragment

A number of studies have already been carried out on the relationship between fine element content and soil carbon content. For example, the work of Pallo *et al.* [27] in southern Burkina Faso showed a significant relationship between carbon stock and particles (clay, clay/silt and sand/clay). To date, very little research has focused on the interdependence between SOCS and the coarse fragments used to calculate these stocks. The work carried out in the Noun plain indicates that, overall, there is a negative and highly significant relationship ($r = -0.470^{**}$) between coarse fragments and SOCS. Results corroborates with those obtained by Zhang *et al.* [46] in the mountainous karst basin in China, where the correlation between gravel content and SOCS revealed a significant difference at the 0.01 threshold with a correlation coefficient greater than 50% ($r = -0.61^{**}$). This is also the case for the results of the work carried out by Pallo *et al.* [27] between coarse fragments and SOC content, where the coefficient of determination admittedly showed a weak interdependence ($R^2 = 0.26^{**}$), but it was still very significant.

Another highly revealing fact from the results of this study carried out in the Noun plain is that the coarse fragment content of Andosols is greater than 50% and the interdependence with carbon stock is highly significant ($R^2 = -0.67^{**}$). On the other hand, for Ferralsols and Acrisols, the proportion of coarse fragments is less than 5% and the interdependence is low and not significant. This result is in line with that of Tsozué *et al.* [31] where the soils studied are characterised by gravel contents of less than 3% and which did not reveal any significant difference with the other parameters of the study. However, other works reveal a significant correlation at the 0.01% threshold between SOCS and coarse fragments with a content greater than 10% [50]. Coarse fragments in a soil influence the storage of organic carbon in that soil by reducing the useful storage volume of the soil [25].

4.3. Dynamics of SOC Stock as a Function of Soil Depth

SOCS in the Noun plain showed a reduction with depth in all nine profiles characterised for this study. The highest average carbon stock was obtained at a depth of 0 - 20 cm (66.3 tC/ha) and the lowest at a depth of 40 - 60 cm (33.3 tC/ha). The result corroborates those reported by Ali *et al.* [51] at the same depth with the same intervals (20 cm) and that of [50] in north-eastern China. This decrease in OC stock from surface to depth is also in line with the work of Saha *et al.* [52], who showed that the variation in total SOCS at different depths is significantly greater at the surface (0 - 15 cm). Similar results have been reported in Egypt [47], in a subhumid climate in Algeria [53], in the upper Magou basin in Benin [15], and on Mount Bambouto in West Cameroon [31], where SOCS decreases with soil depth. Organic carbon in the first metre of soil plays a predominant and crucial role in soil functioning, protection, conservation and sustainable management [54] [55], especially when it is bound to fine soil particles. According to the research results of Atchada *et al.* [15] on the influence of land use patterns on soil organic carbon stocks, there is a strong relationship between the content of fine elements and the soil organic carbon stock according to the four types of land use in their study. They conclude that an increase in the proportion of fine elements favours an increase in organic matter content.

4.4. Dynamics of SOC Stock as a Function of Different Land Use Patterns

Land use is an important factor controlling the storage of OC in soils, as it affects the quantity and quality of litter input, the rate of litter decomposition and the stabilisation processes of organic matter in soils. The results show that the distribution of SOCS depends on the type of land use (**Table 4** and **Figure 2**). In fact, the highest SOCS was obtained in natural formations (58.9 tC/ha) and the lowest stock was obtained in crop fields (42.0 tC/ha). These results are in agreement with those reported in North-West India [52], in North-East Pakistan [51], in Yunnan Province in China [56], in the Cerrado of Brazil [57], and in the mountainous area of North-West Cameroon [6]. This significant variation in SOCS with respect to land use type observed in the Noun agricultural plain is similar to the findings reported by De Blécourt *et al.* [16] in a study on the impact of land use change in Namibia and Zambia.

Figure 2 shows that, regardless of soil type, SOCS in natural formations and agroforest are higher than those in crop fields. This is due to the presence of litter produced by the trees, which is permanently recycled and contributes to the storage of SOC in the first few centimetres of soil. In addition, anthropogenic activities of an agricultural nature in the Noun plain contribute to the continuous removal of crop residues from surface soils, either by export or by burning, which could have led to a lower accumulation of OC in the surface soils of cultivated land. This is in line with the work of Gmach *et al.* [57], whose study focused on assessing different land uses in the Cerrado that could restore soil organic matter levels. This observation was also made by Tegha *et al.* [58], who found in their results that SOC content and stocks were highest in forest land and lowest in arable land, and asserted that converting forest land to small-scale farming increases soil mineralisation, which leads to a reduction in SOC and, consequently, soil degradation. This degradation is the result of tillage, which weakens soil aggregates and thus causes mineralization of soil organic carbon [33] [59].

5. Conclusion

The effect of soil type and land use on SOC storage potential in the subhumid noun plain was the subject of this study. In general, soil type did not have a significant influence on SOC concentration and stocks. With regard to land use type and soil depth, the results showed that SOCS varied significantly ($p < 0.001$) between different land use types and between different depth intervals. SOCS were highest in the upper 0 - 20 cm and lowest in the 40 - 60 cm interval. SOCS therefore decreases with depth in all the profiles studied. Organic carbon storage in the soils of the noun plain is influenced by coarse fragments, which showed a strong and negative correlation with SOCS. The results reported in this study will guide sustainable land management through the preservation of soil organic carbon and to understand the synergies between SOC management and soil health.

Conflicts of Interest

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

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