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Dynamics of soil organic carbon stock under different types of savannah agrosystems in the Sudano-Sahelian zone of Cameroon

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Abstract

The aim of this study was to quantify the current soil organic carbon stock under different types of savannah agrosystems in the Sudano-Sahelian zone of Cameroon in the context of greenhouse gas emissions and land degradation. It is so crucial for combating climate change and improving ecological restoration. Random field sampling was carried out on 0-10, 10-20 and 20-30 cm depth, then were collected in four types of savannah agrosystems. Soil bulk density, pH, moisture content, CEC, exchangeable bases, particle size distribution and soil organic carbon were determined using standard laboratory procedures and calculations. The results of the study did not reveal a significant difference in soil organic carbon stock between different types of savannah agrosystems (P>0.05). Soils of Tamarindus indica savannah agrosystems in recorded higher values SCOS (36.03 ± 3.31 tC/ha), Prosopis africana (33.40 ± 3.27 tC/ha), Haematostaphis barterii (31.83 ± 3.21 tC/ha) and Detarium microcarpum (31.19 ± 3.19 tC/ha) savannah agrosystems. Similarly, SCOS decreased with soil depth in all types of savannah agrosystems. Results showed a positive and significant (P<0.05) correlation between soil organic carbon stock with basal area, biovolume, bulk density, moisture content, C/N ratio, Ca^{2+}, Mg^{2+}, OM; negative and significant (P<0.05) with Soil pH, Total Nitrogen, Na^+ but negative and non-significant (P>0.05) with Density, K^+, CEC, Sand %, Silt %, Clay %, Silt + Clay %. The results show the potential contribution of savannah agrosystems to improve soil organic carbon sequestration and environmental protection.

Keywords: Organic carbon, soil organic carbon stock, carbon sequestration, Savannah agrosystems, Cameroon, climate change.

Introduction

Soil is the loose surface layer of the earth's crust. It is also defined as a natural environment with essentially dynamic properties, differentiated into horizons with mineral and/or organic constituents that are generally loose, resulting from the transformation of an underlying parent rock, under the influence of various chemical, physical and biological processes (FAO, 2017). It is the place where plant roots develop. The increase in population around the world is accompanied by an increase in agricultural production needs,

leading to ever-increasing pressure on impoverishing soils, particularly agricultural soils (FAO, 2017). Today, nearly 40 % of the world's agricultural land has lost its functions such as biological, physical and chemical functions (FAO, 2017). Soil provides physical, chemical and biological habitat for living organisms ; since it regulates water flows, storage and recycling of nutrient cycles and other elements, maintains biological activities and diversity to support plant growth and animal productivity through filtering, buffering, transformation, immobilization and detoxification of organic and inorganic substances it also provides mechanical support to living organisms and their structures (Schmidt et al., 2011; Nibéron, 2016). Ecosystem services include supporting, provisioning, cultural and regulation services (FAO, 2015). For example, those that affect climate, biodiversity, disease, water purification (FAO, 2017). Increasing carbon storage in the form of soil organic matter plays an important role in combating the increase of greenhouse gases in the atmosphere (FAO, 2017). Carbon exists as inseparable components of biomass and soil organic matter (Awé et al., 2020). Its storage in soil organic matter is important in mitigating global climate change and improves the livelihood of resource poor farmers (Moore et al., 2018). It increases land productivity through improved soil properties such as nutrient supply and moisture retention (Bessah et al., 2016). Degradation and deforestation have impacted negatively on both vegetation and soil carbon stock (Bessah et al., 2016). SOC is a vital component of soil with important effects on the functioning of terrestrial ecosystems (Mazarrasa et al., 2018; Rovai et al., 2018). Storage of SOC results from interactions among the dynamic ecological processes of photosynthesis, decomposition, and soil respiration (Spohn, 2020). Soil organic carbon (SOC) is the largest carbon (C) stock in most terrestrial ecosystems, containing approximately 2344 Gt of organic C globally (Stahr et al., 2018). The amount of organic C contained in soils is estimated to be about 1500 billion tones, about twice as much as in the atmosphere and three times as much as in terrestrial vegetation (Stockmann et al., 2013). This carbon mineralizes and returns to the atmosphere with highly variable lifetimes (or storage times), depending on many factors like land use and agricultural practices (FAO, 2015). It is therefore important to know the potential offered by this C reservoir according to practices and uses (FAO, 2017; Lui et al., 2017). Soil carbon sequestration is one way to reduce GHG emissions from agriculture, and the establishment of a market for carbon reduction would allow farmers to gain economic benefit from this process (Hoffmann et al., 2012). Soil organic carbon (SOC) stock has a great importance component in any terrestrial ecosystem, and is any variation in its abundance and composition has important effects on many of the processes that occur within this system (İmamoğlu and Dengiz, 2016; Dengiz et al., 2019). This organic matter generally comes from dead, mainly plant organs and organisms, animal excreta, root exudates and living organisms (Gorham et al., 2020). The organic matter (OM) then undergoes biotransformation in the soil : biodegradation and finally mineralization, which returns the Carbon to the atmosphere in the form of CO_2 (Awé et al., 2019a). Carbon exchanges between the atmosphere and terrestrial ecosystems are about ten times greater than the emissions caused by the use of fossil fuels (FAO, 2017). The biosphere plays an important role in the cycle since a small change in emission or sequestration rates can lead to a major change in the carbon balance. In order to be able to predict climate change and to discover solutions to mitigate or mitigate the problems predicted by experts, it is important to quantify and better understand the GHG dynamics of compartments. Savannah agrosystems represent an important part of the plant community in the Sudano-Sahelian zone of Cameroon. They occupy a very important place in view of their ecological, economic and social values. They play several roles for the user populations, such as feeding the livestock at all times, particularly during periods of food shortage and providing timber and fuelwood. According to our bibliographical investigations, no other work has so far targeted the quantification of soil carbon stock in savannah agrosystems in the Sudano-Sahelian zone of Cameroon. The objective of this study is to assess the soil organic carbon stock in the different savannah agrosystems in the Sudano-Sahelian zone of Cameroon.

Material and Methods

Field Description of the Study area

The study was carried out in the north region (Cameroon). The zone extends between 8° and 10° North latitude and between 12° and 16° East longitude, and is bounded to the North by the Far North region, to the South by the Adamawa region, to the East by the Republics of Chad and Central African Republic and to the West by the Federal Republic of Nigeria (Awé et al., 2019c). The north Cameroon region has a tropical climate of the Sudano-Sahelian type. Average monthly temperatures are between 25.4 and 32.5 °C. Each year, precipitation averages 1003 mm. The relief is a vast pediatric plain between the Mandara Mountains (1,442 m) in the North and the Adamawa Plateau in the South. The soil is of ferruginous type formed by degradation of sandstone from the Middle Cretaceous (Awé et al., 2020). The vegetation encountered is a shrubby Sudanian savannah with a clear and degraded savannah appearance (Awé et al., 2020). The fauna is

rich and very diverse (Awé et al., 2019b). Economic activities concern: agriculture, animal husbandry, fishing, social economy and handicrafts, transport and trade. Agriculture is the main activity of the populations of the North region (Cameroon) (Figure 1).
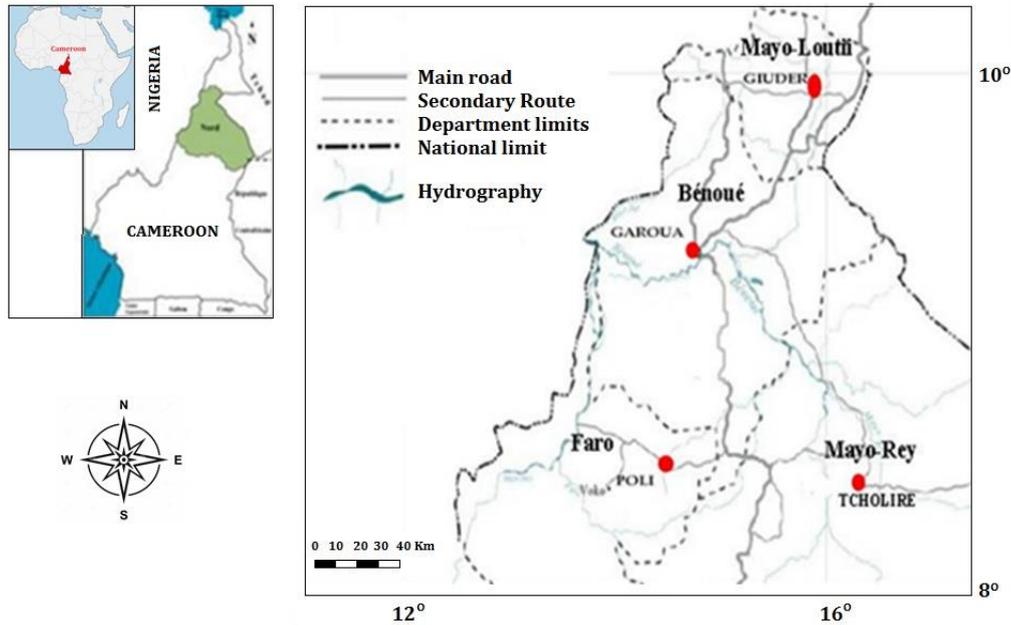
Figure 1. Geographic location of the study area in North Cameroon Region

Data collection

Transects 80 m long by 25 m wide were installed at each site and each transect is spaced 10 m apart. A total of 4 transects were installed for a total sampling area of 1 ha per site. Sampling strips were established using compass, tape measure, GPS and twine. At the ends of each strip, stakes were planted equidistantly 20 m apart. Along the transect, all woody trees of Dbh ≥ 10 cm were surveyed in the four selected savannah agrosystems (*Detarium microcarpum*, *Haematostaphis barterii*, *Prosopis africana* and *Tamarindus indica*). For the calculation of vegetation structure two parameters were taken into account: tree density, basal area and biovolume. For the density of woody plants, we applied the formula below: D= n/S with D: density (trees/ha), n: number of trees present on the area considered and S: area considered (ha). For the basal area, we applied the formulas below: $S = \pi (Di^2/4)$ with S: basal area (m²/ha) and Di: diameter (m). The biovolume is given by the formula of Dawkins (1959): Bv= 0,53 agi x hi x ni with gi: basal area (m²/ha); Hi: height of trees (m); ni: number of trees; Bv: biovolume (m³/ha). According to (Roger and Rabarison, 2000 in Awé et al., 2019c), the biovolume is high when it is above 250 m³/ha, medium when it is between 50 and 250 m³/ha, and low when it is below 50 m³/ha.

Soil samples are taken from January to March. In each 2000 m² survey, soil samples were taken in 0.25 m x 0.25 m frames. These samples are taken at 0-10 cm, 10-20 cm, 20-30 cm depth on the four elementary plots. Each level of soil depth was sampled using a machete and trowel and then immediately put in a closed bag in a cooler, in the shade to avoid evaporation. A total of 3 samples were taken per drilling unit, which corresponds to a total of 12 samples per site and then homogenized to obtain an aggregate sample. A total of 48 samples (4 sites x 3 depths x 4 replicates x 1 area) for all four sites were dug into the ground to a depth of 30 cm. Once all samples were collected, they were taken for laboratory analysis. The laboratory method consists of determining, evaluating or measuring the physico-chemical parameters of the soils:

Bulk density

The determination of the bulk density was carried out by sampling a defined volume of soil using a cylinder driven into the ground. After drying the sample in an oven at 105°C for 48 hours, it was weighed again. The dry weight of the sample P divided by the sample volume (V) gave the bulk density (Da) in g/cm³. It is calculated using the following formula Da=P/V; was done according to the NF ISO 11464 Standard (AFNOR, 2006).

Determination of pH

The pH measurement was carried out on a sol-water solution for the pH water and a sol-KCL solution for the pH in a ratio of 1/2.5 using a PH-meter with a glass electrode. The pH meter was previously calibrated using the standard solutions according to the NF ISO 10390 standard (AFNOR, 2005).

Determination of the moisture content at 105°C

The moisture content at 105°C which allows to estimate the water content was done according to the NF X15-110 standard (AFNOR, 1994). It consists in introducing 5 g of the fresh sample into a previously tared flask, then let the soil sample dry in the oven at 105°C for 24 h; then let it cool in a desiccator and weigh. The equivalent moisture is thus determined by the following formula: H= (P gross air-dried) - (P gross air-dried at 105°C) / (P net air-dried) x 100.

Soil texture analysis

Soil texture analysis was determined by the Robinson's pipette method on air-dried soil samples sieved at 2mm. The organic matter was previously destroyed by attack with hydrogen peroxide. The sol was then dispersed by rotary shaking in flasks after addition of sodium hexa-metaphosphate $(NaPO_3)_6$. The different particle size fractions were determined by pipetting for the clayey and silty fractions and by sieving for the sand (AFNOR, 2003).

Determination of Total Nitrogen

The total Nitrogen was obtained through the (Kjeldahl, 1883) method after heat treatment of the sample with a mixture of sulphuric acid (H_2SO_4) and salicylic acid $(C_6H_4(COOH)(OH)$. The nitrates present in the sample were first fixed by the salicylic acid and then reduced to ammonia by the use of a catalyst consisting of copper sulphate $(CuSO_4)$. The distillate was captured in boric acid (H_3BO_3) and then titrated with sulphuric acid (H_2SO_4) according to the NF EN ISO 23470 Standard (AFNOR, 2011).

Determination of Exchangeable Bases

Exchangeable bases were extracted from the soil with a solution of Ammonium Acetate $(C_2H_3O_2NH_4)$ at pH7. The concentrations were made by atomic absorption spectrometry (Magnesium) and by flame emission (Calcium, Potassium, Sodium) according to the NF X31-108 standard (AFNOR, 2002). The K, Mg, Na and Ca contents are converted into kg/ha.

Cationic exchange capacity (CEC): This was done with ammonium acetate at pH7 and notably in three phases: saturation of the absorbent complex by NH_4^+ ions and extraction of the exchangeable bases; washing of the soil with alcohol in order to eliminate excess NH_4^+ ions; determination of NH_4^+ by Kjéldahl distillation after desorption from a KCL solution according to the NF EN ISO 23470 standards (AFNOR, 2011).

Soil organic carbon was determined by (Walkley and Black, 1934) method, which is an oxidation with potassium bicarbonate $(K_2Cr_2O_7)$ in an acid medium (H_2SO_4) according to the NF ISO 14235 standard (AFNOR, 1998). The dosage was done by calorimetry. The organic matter content was obtained by multiplying the organic carbon rate by the Sprengel factor which is 1.724 for cultivated soils and 2 for uncultivated soils. Soil carbon (SCOS) (tC/ha) = Da. (% COS). S. P (Awé et al., 2020) with Da: bulk density in tones /m^3; COS%, organic carbon content of the soil; S: area in m^2; p: depth m.

Data analysis

The data were encoded in EXCEL software and then analyzed using STATGRAPHICS plus 5.0 and R software. Correlation and significance tests were performed using ANOVA and Duncan's 5 % test.

Results and Discussion

Soil physical characteristics

The highest density was recorded in Detarium microcarpum (310 ± 10.10 stems/ha) savannah agrosystems (Table 1). This high density means that the stems used to reconstitute the environment are shrubs. This result lies in the range 208 ± 8.57 - 408 ± 11.12 individuals/ha found by (Awé et al., 2019c) in savannah agrosystems in the Sudano-Sahelian zone of Cameroon. The highest values of basal area (11.50 ± 1.65 m^2/ha) and biovolume (48.65 ± 3.95 m^3/ha) were recorded in the Tamarindus indica savannah agrosystems (Table 1). This indicates the existence of large specimen trees on the one hand and a significant timber potential due to their large diameters on the other. The basal area and biovolume values obtained in this work are respectively in the range, 2.94 ± 0.13 - 11.56 ± 0.57 m^2/ha and 32.94 ± 3.03 - 116.78 ± 16.57 m^3/ha found by (Awé et al., 2019c) in savannah agrosystems in the Sudano-Sahelian zone of Cameroon. The analysis of variance shows that there is no significant difference in density (P=0.321), basal area (P=0.123) and biovolume (P=0.532) between the different types of savannah agrosystems studied (Table 1).

Table 1. Structural characterization of the different savannah agrosystems

Savannah agrosystems	Density (stems/ha)	Basal area (m^2/ha)	Biovolume (m^3/ha)
Detarium microcarpum	310 ± 10.10a	8.33 ± 1.01a	33.43 ± 2.05a
Haematostaphis barterii	278 ± 8.98a	10.42 ± 1.35a	36.53 ± 3.15a
Prosopis africana	202 ± 8.14a	10.55 ± 1.42a	37.65 ± 3.63a
Tamarindus indica	138 ± 5.93a	11.50 ± 1.65a	48.65 ± 3.95a

Values assigned the same letter are not statistically different (p > 0.05; Duncan's test)

The granulometric distribution made it possible to distinguish 4 textural classes including clay- sandy, fine silt, clayey and clay-silt soils. The analysis of variance relating to soil textural fractions (Clay: P = 0.0268; Silt: P = 0.0000 and sand: P = 0.0004) show that there is a variation in soil textural composition according to the different savannah agrosystems studied (Table 2). In fact, clay soils have a more acidic pH than sandy soils (Carrier, 2003).

Table 2. Soil texture under the different savannah agrosystems

Textural fractions	*Detarium microcarpum*	*Haematostaphis barterii*	*Prosopis africana*	*Tamarindus indica*
Sand, %	12 ± 1.50a	18 ± 2.88b	38.43 ± 6.35d	31 ± 4.95c
Silt, %	42 ± 8.54b	63 ± 15.03c	15.89 ± 2.38a	37 ± 8.80b
Clay, %	46 ± 5.46c	19 ± 2.92a	45.68 ± 5.44c	32 ± 3.04b
Textural classes	Sandy clay	Fine silt	Clayey	Clay loam

Values assigned the same letter are not statistically different (p > 0.05; Duncan's test)

Bulk density varies with depth. The highest values of the bulk density values were recorded at depths of 0-10 cm. The highest bulk density value was recorded to Tamarindus indica (1.61 ± 0.16 g/cm³) savannah agrosystems. This may be due to soil compaction which is contrary to the other three in the savannah agrosystems studied where the soil is loosened due to fine root mat, microbial and arthropod activities leading to soil aeration. The analysis of variance shows that there is no significant difference between depths (P=0.085) on the one hand and between savannah agrosystems (P=0.065) on the other hand (Table 3).

Table 3. Variation in bulk density as a function of depth under different savannah agrosystems

Depths (cm)	*Detarium microcarpum*	*Haematostaphis barterii*	*Prosopis africana*	*Tamarindus indica*
0-10	1.58 ± 0.10a	1.59 ± 0.11a	1.63 ± 0.15a	1.68 ± 0.15a
10-20	1.43 ± 0.12a	1.44 ± 0.13a	1.53 ± 0.15a	1.58 ± 0.16a
20-30	1.15 ± 0.14a	1.17 ± 0.15a	1.22 ± 0.16a	1.28 ± 0.17a
Mean	1.25 ± 0.12A	1.43 ± 0.13A	1.53 ± 0.15A	1.61 ± 0.16A

Values assigned the same letter are not statistically different (p > 0.05; Duncan's test)

Moisture content varies with depth. The highest values of humidity were recorded at depths of 20-30 cm. Among savannah agrosystems, the highest value was recorded in Tamarindus indica (27.61 ± 2.39) savannah agrosystems. This may be influenced by the vegetation cover; Detarium microcarpum savannah agrosystems being much more exposed to solar radiation. The texture of these soils may also influence its moisture content. Indeed, a sandy soil allows water to pass easily while a clay soil retains water (Coudurier and Bourgogne, 2012). As for pH, it is more acidic in forest soils. Tree growth involves taking ions from the soil and releasing others with identical electrical charges in order to maintain their electrical balance (Munguakonkwa, 2018). Since they require more cations than anions, their growth releases many cations (often H^+) into the soil, making it more acidic (Ranger, 2018). The analysis of variance shows that there is no significant difference between depths (P=0.238) on the one hand and between savannah agrosystems (P=0.312) on the other hand (Table 4).

Table 4. Variation of moisture content as a function of depth under different savannah agrosystems

Depths (cm)	*Detarium microcarpum*	*Haematostaphis barterii*	*Prosopis africana*	*Tamarindus indica*
0-10	20.18 ± 2.31a	21.33 ± 2.33a	22.43 ± 2.33a	25.53 ± 2.35a
10-20	22.23 ± 2.32a	23.42 ± 2.35a	24.53 ± 2.35a	26.63 ± 2.38a
20-30	25.35 ± 2.36a	26.55 ± 2.37a	28.65 ± 2.38a	30.68 ± 2.44a
Mean	22.58 ± 2.33A	23.76 ± 2.35A	25.20 ± 2.35A	27.61 ± 2.39A

Values assigned the same letter are not statistically different (p > 0.05; Duncan's test)

Soil chemical characteristics

Soil reaction (pH) varies with depths. The highest values of the soil reaction were recorded at depths of 0-10 cm. Among savannah agrosystems, the highest value was recorded in the Detarium microcarpum (pH = 6.42 ± 1.42) savannah agrosystems. This can be explained by clearing by burning which brings large amounts of ash to the soil which can increase the initial pH. This result is in the range 4.5 to 6.5 (Dabin, 1985). The analysis of variance shows that there is no significant difference between depths (P=0.505) on the one hand and between savannah agrosystems (P=0.192) on the other hand (Table 5).

Table 5. Variation of pH as a function of depth under different savannah agrosystems

Depths (cm)	*Detarium microcarpum*	*Haematostaphis barterii*	*Prosopis africana*	*Tamarindus indica*
0-10	6.88 ± 1.50a	6.72 ± 1.33a	6.73 ± 1.65a	5.58 ± 1.47a
10-20	6.65 ± 1.44a	6.55 ± 1.35a	5.65 ± 1.26a	5.33 ± 1.46a
20-30	5.73 ± 1.32a	5.93 ± 1.23a	5.53 ± 1.35a	5.23 ± 1.34a
Mean	6.42 ± 1.42A	6.40 ± 1.30A	5.97 ± 1.28A	5.38 ± 1.25A

Values assigned the same letter are not statistically different (p > 0.05; Duncan's test)

The analysis of variance did not show a significant difference in nitrogen content between savannah agrosystems (P=0.544). Soils in Detarium microcarpum savannah agrosystems had the highest values of nitrogen content (6.64 ± 1.31 kg/ha). At only 5%, analysis of variance (P=0.360) did not reveal a significant difference between the C/N ratios of the different savannah agrosystems studied. Soils in Tamarindus indica savannah agrosystems have the highest C/N ratios (12.76 ± 5.03) (Table 6). Soils of Detarium microcarpum savannah agrosystems have a low biological activity (C/N greater than 12) and therefore a slow rate of OM decomposition, whereas for Detarium microcarpum, Haematostaphis barterii, Prosopis africana savannah agrosystems, this rate is higher with normal values (C/N between 8 and 12). Several other factors would explain these variations in C/N ratios such as particle size and pH (Decoopman et al., 2013).

Table 6. Total nitrogen and C/N ratio under the different savannah agrosystems

	Detarium microcarpum	Haematostaphis barterii	Prosopis africana	Tamarindus indica
Total Nitrogen (Kg/ha)	6.64 ± 1.31a	5.54 ± 1.28a	4.34 ± 1.15ab	4.05 ± 1.08a
C/N ratio	8.44 ± 2.20a	8.88 ± 2.54a	8.98 ± 2.38a	12.76 ± 5.03b

Values assigned the same letter are not statistically different (p > 0.05; Duncan's test)

Potassium (K^+), sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) contents of soils are higher in Detarium microcarpum savannah agrosystems with values of 47 ± 10.07; 16 ± 4.20; 22.1 ± 6.09 and 57.1 ± 15.30 Kg/ha respectively. At only 5 %, the analysis of variance revealed no significant difference in soil (K^+; P=0.433), (Na^+; P=0.542) and (Ca^{2+}; P=0.213) contents between the different savannah agrosystems studied. The analysis of variance revealed significant difference in soil (Mg^{2+}; P=0.410) contents between the different savannah agrosystems studied. The cation exchange capacity (CEC) of soils is higher in Tamarindus indica savannah agrosystems (24.72 ± 4.99 Kg/ha). The analysis of variance shows a significant difference in soil cation exchange capacity (CEC) (P=0.002) between different savannah agrosystems studied at the 5 % threshold (Table 7).

Table 7. Variation in exchangeable bases and CEC under the different savannah agrosystems

Parameters	Detarium microcarpum	Haematostaphis barterii	Prosopis africana	Tamarindus indica
K^+ (Kg/ha)	47 ± 10.07b	24 ± 10.04a	15 ± 10.06a	12 ± 10.01a
Na^+ (Kg/ha)	16 ± 4.20a	15 ± 4.16a	14 ± 4.12a	11 ± 4.10a
Ca^{2+} (Kg/ha)	22.1 ± 6.09bc	18.1 ± 6.05b	18.6 ± 6.06b	3.9 ± 1.03a
Mg^{2+} (Kg/ha)	57.1 ± 15.30d	38.5 ±10.08c	16.3 ± 5.12b	9.8 ± 2.23a
CEC (Kg/ha)	12.96 ± 1.09a	16.58 ± 2.23b	20.84 ± 3.76c	24.72 ± 4.99d

Values assigned the same letter are not statistically different (p > 0.05; Duncan's test)

Soil organic matter content in the savannah agrosystems studied decreased with depth of sampling. The highest values of soil organic matter content were observed at a depth of 0-10 cm. Detarium microcarpum Savannah agrosystems had the highest values of soil organic matter content (2.34 ± 0.13). The analysis of variance did not reveal any significant difference in soil organic matter content between depths on the one hand (P= 0.553) and between savannah agrosystems on the other (P= 0.548) (Table 8).

Table 8. Variation in organic matter content (OM) as a function of depth under different savannah agrosystems

Depths (cm)	Detarium microcarpum	Haematostaphis barterii	Prosopis africana	Tamarindus indica
0-10	2.45 ± 0.15a	2.47 ± 0.13a	2.48 ± 0.12a	2.58 ± 0.10a
10-20	2.23 ± 0.12a	2.24 ± 0.11a	2.25 ± 0.11a	2.39 ± 0.10a
20-30	2.00 ± 0.10a	2.05 ± 0.10a	2.08 ± 0.11a	2.11 ± 0.10a
Mean	2.34 ± 0.13A	2.23 ± 0.11A	2.21 ± 0.11A	2.16 ± 0.10A

Values assigned the same letter are not statistically different (p > 0.05; Duncan's test)

Soil organic carbon stocks

The highest values of soil organic carbon stocks were observed at a depth of 0-10 cm. The analysis of variance did not reveal any significant difference in soil organic carbon stocks between depths on the one hand (P= 0.207) and between savannah agrosystems on the other hand (P= 0.261) (Table 9). Soils in Tamarindus indica savannah agrosystems (36.03 ± 3.31 tC/ha) are those that store more carbon than those in other types of savannah agrosystems. This result is in the range 24.65 ± 2.51- 42.97 ± 4.35 tC/ha reported by (Awé et al., 2019c) for Burkea africana savannah agrosystems in the sudano-sahelian zone of Cameroon. Vegetation types can alter soil carbon stocks due to several key factors, including litterfall and root turnover, soil chemistry, root exudates, and microclimate (Ontl and Schulte, 2012; Awé et al., 2019c). Low carbon stocks of Detarium microcarpum savannah agrosystems are explained by the fact that agricultural practices such as deforestation, turning and frequent tillage, etc., cause a decrease in soil carbon stock (Swiderski et al., 2012). The maximum depth of 0 to 10 cm recorded the highest soil organic carbon stock under all types of savannah agrosystems (Bessah et al., 2016; Awé et al., 2019c; Awé et al., 2020).

Table 9. Variation in organic carbon stock as a function of depth under different savannah agrosystems

Depths (cm)	Detarium microcarpum	Haematostaphis barterii	Prosopis africana	Tamarindus indica
0-10	38.71 ± 3.31a	39.27 ± 3.33a	40.42 ± 3.38a	43.34 ± 3.45a
10-20	31.88 ± 3.20a	32.25 ± 3.22a	34.42 ± 3.25a	37.76 ± 3.28a
20-30	23.00 ± 3.06a	23.98 ± 3.10a	25.37 ± 3.18a	27.00 ± 3.22a
Mean	31.19 ± 3.19A	31.83 ± 3.21A	33.40 ± 3.27A	36.03 ± 3.31A

Values assigned the same letter are not statistically different (p > 0.05; Duncan's test)

Relationship between soil organic carbon stock and soil pysico-chemical characteristis

Soils with high carbon stock are clay loam soils (36.03 ± 3.31 tC/ha) followed by clay soils (33.40 ± 3.27 tC/ha); fine loam soils (31.83 ± 3.21 tC/ha) and clay-sandy soils (31.19 ± 3.19 tC/ha). The analysis of variance did not reveal a significant difference in soil carbon stock between textural classes (P= 0.164) (Figure 2).

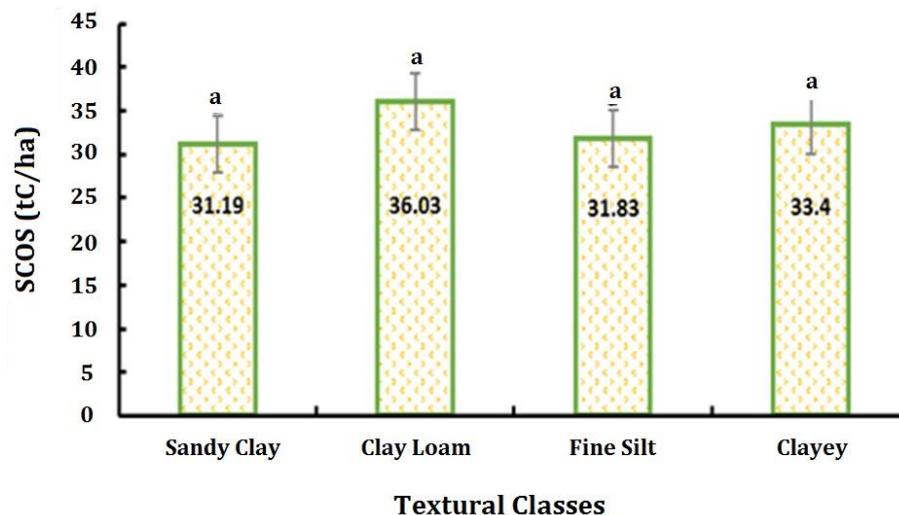Figure 2. Organic carbon stocks by soil textural classes. Values assigned the same letter are not statistically different (p > 0.05; Duncan's test).

Results showed a positive and significant correlation (P<0.05) between soil organic carbon stock with basal area, biovolume, bulk density, moisture content, C/N ratio, Ca^{2+}, Mg^{2+}, OM (Table 10). This marks a dependence effect in the variation of SCOS. Also the negative and significant (P<0.05) correlation with Soil pH, Total Nitrogen, Na^+ would show an inverse and dependence effect with SCOS (Table 10). Finally, the negative and non-significant correlation (P>0.05) of SCOS with Density, K^+, CEC would not reflect any dependence effect (Table 10). Results showed a negative and non-significant (P>0.05) correlation between soil organic C stock with % Sand, % Silt, % Clay, % Silt + Clay according to the three depth ranges of 0-10 cm, 10-20 cm and 20-30 cm respectively (Table 10). Soil organic carbon stocks decreased with increasing depth in all types of savannah agrosystems, as indicated in several results (Agboadoh, 2011; Jiao et al., 2012; Bessah et al., 2016; Awé et al., 2019c). On the other hand, there is no correlation between the density of savannah agrosystems and the amount of organic carbon sequestered in the soil. This can be explained by the presence of large trees in the savannah agrosystems studied. Organic carbon stock depends on basal area and biovolume in savannah agrosystems.

Conclusion

This study gives us a better understanding of the soil organic carbon stock in the savannah agrosystems studied. Soil is a non-renewable resource whose quality must therefore be preserved for its environmental functions. The results show that the soil organic carbon stock is higher in Tamarindus indica savannah agrosystems. However, the evolution of COS stocks is more or less decreasing as the savannah agrosystems evolve. From all the soil physico-chemical parameters measured, only bulk density, moisture content, C/N ratio, Ca^{2+}, Mg^{2+}, OM show a strong and positive linear correlation with soil carbon stock among all the physico-chemical parameters measured. Soil physico-chemical parameters (texture, total nitrogen, C/N ratio, pH, soil bulk density, moisture content, CEC, exchangeable bases) also vary according to the types of savannah agrosystems.

Table 10. Pearson correlation (R^2) result of SCOS with other parameters

Parameters	Soil organic carbon stocks		
	0-10 cm	10-20 cm	20-30 cm
Density	-0.18ns	-0.14ns	-0.23ns
Basal area	0.98***	0.93***	0.96***
Biovolume	0.98***	0.97***	0.98***
Bulk density	0.89***	0.90***	0.89***
Soil pH	-0.94***	-0.96***	-0.98***
Moisture (%)	0.98***	0.98***	0.98***
Total Nitrogen (Kg/ha)	-0.88***	-0.85***	-0.87***
C/N (%)	0.75*	0.71*	0.78*
K^+ (Kg/ha)	-0.28ns	-0.29ns	-0.27ns
Na^+ (Kg/ha)	-0.98***	-0.98***	-0.98***
Ca^{2+} (Kg/ha)	0.97***	0.98***	0.96***
Mg^{2+} (Kg/ha)	0.72**	0.70**	0.71**
CEC (Kg/ha)	-0.32ns	-0.41ns	-0.28ns
OM (%)	0.88***	0.85***	0.87***
% Sand	0.24ns	0.21ns	0.23ns
% Silt	0.22ns	0.24ns	0.26ns
% Clay	0.28ns	0.25ns	0.30ns
% Silt + Clay	0.38ns	0.31ns	0.29ns

Coefficients at p<0.05 are significantly correlated; *: p≤0.05; **: p≤0.01; ***: p≤0.001 (Pearson test); ns: not significant

Acknowledgment

References

AFNOR, 1994. Qualité du sol et détermination du taux d'humidité à 105°C (NF X15-110). [in French].

AFNOR, 1998. Qualité du sol et dosage du carbone organique par oxydation sulfochromique ou au bicarbonate de potassium (NF ISO 14235). [in French].

AFNOR, 2002. Qualité des sols, détermination des cations : Ca^{++}, Mg^{++}, K^+, Na^+ extractibles par l'acétate d'ammonium et méthode par agitation (NF X31-108). [in French].

AFNOR, 2003. Qualité du sol, détermination de la distribution granulométrique des particules du sol et méthode à la pipette (NF X31-107).

AFNOR, 2005. Qualité du sol et détermination du pH (NF ISO 10390). [in French].

AFNOR, 2006. Qualité du sol et prétraitement des échantillons pour analyses physico-chimiques (NF ISO 11464). [in French].

AFNOR, 2011. Qualité du sol et détermination de la capacité d'échange cationique (CEC) effective et des cations échangeables à l'aide d'une solution de trichlorure de cobaltihexammine (NF EN ISO 23470). [in French].

Agboadoh, D.M.Y., 2011. Soil organic carbon stocks in croplands of the Bechem Forest District, Ghana (Unpublished master's thesis). Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Alex, D., Rollin, A., 2017. Gestion de la MO et des flux de carbone en grandes cultures et prairies. 28p. [in French]. Available at [Access date: 01.05.2020]: https://agriculture-de-conservation.com/sites/agriculture-de-conservation.com/IMG/pdf/travail-phytotechnie-1m-dumoulin-rollin.pdf

Awé, D.V., Noiha, N.V., Zapfack, L., 2020. Carbon Storage and emission factor of Savanna ecosystems in Sudano-Sahelian zone of Cameroon. *Journal of Botany Research* 2(1): 60-67.

Awé, D.V., Noiha, N.V., Zapfack, L., Ali, A.D., Madou, C., 2019b. Carbon stocks in dead wood biomass of Savannah ecosystems in Northern Region Cameroon. *Journal of Botany Research* 2(1): 60-70.

Awé, D.V., Noiha, N.V., Zapfack, L., Vroh, B.T.A., Nyeck, B., 2019c. Vegetation structure, root biomass distribution and soil carbon stock of Savannah agrosystems in Sudano-Sahelian Zone of Cameroon. *Journal of Botany Research* 2(1): 71-80.

Awé, D.V., Noiha, N.V., Zapfack, L., Vroh, B.T.A., Saïdou, A., 2019a. Carbon sequestration potential and economic value in agroforestry parkland to Tectona grandis L. f. (Verbenaceae) in Central Africa: A case study to Department of Poli (Northern Region in Cameroon). *Advances in Research* 18(5): 1-16.

Bessah, E., Bala, A., Agodzo, S.K., Okhimamhe, A.A., 2016. Dynamics of soil organic carbon stocks in the Guinea savanna and transition agro-ecology under different land-use systems in Ghana. *Cogent Geoscience* 2(1) : 1140319.

Carrier, A., 2003. Que Se Passe-t-Il Dans Le Sol?. *Serriculture Maraichère Biologique*. 9p. [in French]. Available at [Access date: 01.05.2020]: https://www.agrireseau.net/legumesdeserre/Documents/QUE%20SE%20PASSE-T-IL%20DANS%20SOL%20(AC)%20-%2003-03-31.PDF

Coudurier, C., Bourgogne, A., 2012. Guide Pédologique: Les Sols. 34p. [in French]. Available at [Access date: 01.05.2020]: https://www.alterrebourgognefranchecomte.org/_depot_alterrebourgogne/_depot_arko/basesdoc/4/14145/guide-pedago-les-sols.pdf

Dabin, B., 1985. Les sols tropicaux acides : Cah. ORSTOM, *Série de Pédologie* 21(1):7–19. [in French].

Dawkins, H.C., 1959. The volume increment of natural tropical high forest and limitations on its improvement. *Empire Forest Review* 38(2): 175-180.

Decoopman, B., Hanocq, D., Heddadj, D., Dibet, A., 2013. Tout Ce Que Vous Avez Toujours Voulu Savoir Sur Le Sol. *TERRA*. 33p. [in French]. Available at [Access date: 01.05.2020]: https://agriculture-de-conservation.com/sites/agriculture-de-conservation.com/IMG/pdf/sol-bretagne.pdf

Dengiz, O., Saygın, F., İmamoğlu, A., 2019. Spatial variability of soil organic carbon density under different land cover and soil types in a sub-humid terrestrial ecosystem. *Eurasian Journal of Soil Science* 8(1): 35 – 43.

FAO, 2015. Learning tool on nationally appropriate mitigation actions (NAMAs) in the agriculture, forestry and other land use (AFOLU) sector. Food and Agriculture Organization of the United Nations, Rome, Italy. 90p. Available at [Access date: 01.05.2020]: http://www.fao.org/3/a-i4642e.pdf

FAO, 2017a. Soil Organic Carbon: the hidden potential. Food and Agriculture Organization of the United Nations, Rome, Italy. 90p. Available at [Access date: 01.05.2020]: http://www.fao.org/3/a-i6937e.pdf

Gorham, C., Lavery, P., Kelleway, J.J., Salinas, C., Serrano, O., 2020. Soil Carbon Stocks Vary Across Geomorphic Settings in Australian Temperate Tidal Marsh Ecosystems. *Ecosystems* [in Press]

Hoffmann, U., Yair, A., Hikel, H., Kuhn, N.J., 2012. Soil organic carbon in the rocky desert of northern Negev (Israel). *Journal of Soils and Sediments* 12: 811-825.

İmamoğlu, A., Dengiz, O., 2016. Determination of soil erosion risk using RUSLE model and soil organic carbon loss in Alaca catchment (Central Black Sea Region, Turkey)*. Rendiconti Lincei* 28(1): 11-23.

Jiao, Y., Xu, Z., Zhao, J., Yang, W., 2012. Changes in soil carbon stocks and related soil properties along a 50-year grassland-to-cropland conversion chronosequence in an agro-pastoral ecotone of Inner Mongolia, China. *Journal of Arid Land* 4(4): 420–430.

Kjeldahl, J., 1883. Neue Methode zur Bestimmung des Stickstoffs in organischen Körpern. *Zeitschrift für analytische Chemie* 22(1): 366-382.

Liu, J., Bowman, K.W., Schimel, D.S., Parazoo, N.C., Jiang, Z., Lee, M., Bloom, A.A., Wunch, D., Frankenberg, C., Sun, Y., O'Dell, C.W., Gurney, K.R., Menemenlis, D., Gierach,M., Crisp, D., Eldering, A., 2017. Contrasting carbon cycle responses of the tropical continents to the 2015–2016 El Niño. *Science* 358(5690): aam5690.

Mazarrasa, I., Samper-Villarreal, J., Serrano, O., Lavery, P.S., Lovelock, C.E., Marbà, N., Duarte, C.M., Cortés, J., 2018. Habitat characteristics provide insights of carbon storage in seagrass meadows. *Marine Pollution Bulletin* 134: 106–117.

Moore, B., Kaur, G., Motavalli, P., Zurweller, B., Svoma, B., 2018. Soil greenhouse gas emissions from agroforestry and other land uses under different moisture regimes in lower Missouri River Floodplain soils: a laboratory approach. *Agroforestry Systems* 92: 335-348.

Munguakonkwa, C.M., 2018. Etude de la variation de stocks de carbone dans le sol forestier suivant le type d'utilisation de terre à Tshivanga au PNKB. Mémoire d'ingénieur Agronome Option : Eaux et forêts, Université catholique de Bukavu. pp.63.

Nibéron, C., 2016. La Séquestration Du Carbone Dans Les Sols. *France-Sciences.* 4p. [in French].

Ontl, T.A., Schulte, L.A., 2012. Soil Carbon Storage. *Nature Education Knowledge* 3(10):35.

Ranger, J., 2018. La fertilité des sols forestiers : quels sont ses déterminants ? 4p La Forêt et le Bois en France en 100 Questions. [in French]. Available at [Access date: 01.05.2020]: https://www.academie-foret-bois.fr/app/download/15649034624/2.03.+fertilite%CC%81.pdf?t=1579071403

Roger, E., Rabarison, H., 2000. Contexte biologique de la conservation des forêts à Madagascar. Etude sur la politique de conservation des ressources forestières à Madagascar, 53p. [in French].

Rovai, A.S., Twilley, R.R., Castañeda-Moya, E., Riul, P., Cifuentes-Jara, M., Manrow-Villalobos, M., Horta, P.A., Simonassi, J.C., Fonseca, A.L., Pagliosa, P.R., 2018. Global controls on carbon storage in mangrove soils. *Nature Climate Change* 8: 534-538.

Schmidt, M.W.I., Torn, M.S., Abive, S., Dittimar, T., Guggenberger, G., Janssens, IA., Kleber, M., Kogel-Knabner, I., Lehmann, J., Manning, D.A.C., Nannipieri, P., Rasse, D.P., Weiner, S., Trumbore, S.E., 2011. Persistence of soil organic matter as an ecosystem property. *Nature* 478: 49-56.

Spohn, M., 2020. Phosphorus and carbon in soil particle size fractions: A synthesis. *Biogeochemistry* 147: 225–242.

Stahr, S., Graf-Rosenfellner, M., Klysubun, W., Mikutta, R., Prietzel, J., Lang, F., 2018. Phosphorus speciation and C:N:P stoichiometry of functional organic matter fractions in temperate forest soils. *Plant and Soil* 427(1–2):53–69.

Stockmann, U., Adams, M.A., Crawford, J.W., Field, D.J., Henakaarchchi, N., Jenkins, M., Minasny, B., McBratney, A.B., Courcelles, V.R., Singh, K., Wheeler, I., Abbott, L., Angers, D.A., Baldock, J., Bird, M., Brookes, P.C., Chenu, C., Jastrow, J.D., Lal, R., Lehmann, J.O., Donnell, A.G., Parton, W. J., Whitehead, D., Zimmermann, M., 2013. The

knowns, known unknowns and unknowns of sequestration of soil organic carbon. *Agriculture, Ecosystems and Environment* 164: 80-99.

Swiderski, C., Saby, N.P.A., Party, J.P., Sauter, J., Köller, R., Vandijk, P., Lemercier, B., Arrouays, D., 2012. Evolution des teneurs en carbone organique dans l'horizon de surface des sols cultivés en Alsace : Analyse à partir de la Base de Données de Analyses de Terre. *Etude et Gestion des Sols* 19(3) :179-192. [in French].

Walkley, A., Black, C.A., 1934. An examination of Digestion method for determining soil organic matter and proposed modification of the chromic acid titration method. *Soil Science* 37(1): 29-38.

Youl, S., 2005. Dynamique et modélisation de la dynamique du carbone dans un agrosystème de savane de l'Ouest du Burkina Faso. Thèse de doctorat unique, Université Polytechnique de Bobo Dioulasso (UPS) du Burkina Faso. 144p. [in French].