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Soil Organic Carbon Stock under Different Age Ranges of Cashew Agroecosystems 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 age ranges of cashew agroecosystems 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 depths were collected in three age groups (0-10; 10-20; over 20 years old) of Cashew agroecosystems. Soil bulk density, Soil reaction (pH), moisture content, total nitrogen, C/N ratio, 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 across the different age groups of the cashew agroecosystems (P>0.05). The highest values of soil organic carbon stocks were observed in the 0-10 cm depth. Soils under plots with over 20 cashew agroecosystems in Bénoué subdivisions recorded higher SOCS values (36.30±2.92 tC/ha). Similarly, the SOCS decreased with soil depth in all three age groups of Cashew agroecosystems. The mean SOC concentrations (%) ranged from 0.20±0.02-0.41±0.10%. Soil organic carbon stock ranged from 16.45±0.73-37.04±2.32 tC/ha depending on depth between the three age ranges of Cashew agroecosystems studied in the four subdivisions. The Cashew agroecosystems soils with high C stock are those with sandy loamy texture (25.79±2.29 tC/ha). Results showed a positive and significant (P<0.05) correlation between soil organic C stock with bulk density, moisture content, C/N ratio, SOC; negative and significant (P<0.05) with Soil reaction (pH), Total Nitrogen, but negative and non-significant (P>0.05) with % Sand, % Silt, % Clay, % Silt + Clay. The results show the potential contribution of Cashew agroecosystems to improve soil organic carbon sequestration and environmental protection. This information will be necessary for developing appropriate technological and political solutions to increase agricultural sustainability and combat environmental degradation in the Sudano-Sahelian zone of Cameroon.

Keywords: Cameroon, Cashew, Carbon, Soil Organic Carbon Stocks

Introduction
Carbon dioxide (CO₂) is the main Greenhouse Gas (GHG) linked to human activities (FAO, 2017). Globally, nearly 35 billion tons of CO₂ were emitted in 2013 by the consumption of fossil oil, gas or coal reserves and by the production of cement (FAO, 2017). Terrestrial ecosystems mitigate the impact of these emissions by capturing more than a third of them through photosynthesis. Soil organic matter is the most important reservoir of organic carbon, ahead of plant biomass (Dengiz et al., 2019). Greenhouse gases are
gaseous components of the atmosphere, both natural and anthropogenic and whose properties are responsible for the greenhouse effect (Victor et al., 2020). Carbon is the major constituent of two greenhouse gases, CO₂ and CH₄, without which there could be no life on earth; its recycling particularly influences biological productivity and the climate (Dass et al., 2018). The organic carbon stock present in natural soils presents a dynamic balance between the contributions of plant debris and animal excrement and the loss due of decomposition (Wang et al., 2020). Not all soils store the same amount of carbon depending on their nature and especially their use. Thus, limiting plowing or maintaining the forest improves carbon storage in the soil. Plants absorb carbon from CO₂ in the air of photosynthesis (FAO, 2017). The plant photosynthesis consists in reducing carbon dioxide from the atmosphere by the water absorbed by the roots using solar energy captured by the leaves, in the presence of mineral salts, with the release of oxygen, in order to produce carbohydrates (Bossio et al., 2020).

Lefèvre et al. (2017), the main greenhouse gas responsible for climate change from global warming in the Earth's atmosphere are water vapor (H₂O), Carbon dioxide (CO₂), Nitrous Oxide (N₂O), methane (CH₄) and Ozone (O₃). This warming is associated with an unprecedented increase in anthropogenic GHG emissions since pre-industrial times, mainly due to economic and population growth (FAO, 2017). In addition, these climate changes are unprecedented in speed of global rates; at least for more than 1000 years (Smith et al., 2015). The carbon sequestration by soils is a way to reduce GHG emissions from agriculture and the establishment of a market for reducing carbon emissions would allow farmers to benefit economically from this process. Soil is for this purpose a very important reservoir of Carbon (C).

The carbon sequestered by the soil remains in the form of organic compounds (Schlesinger and Amundson, 2019). This organic matter usually comes from dead bodies and organizations, mainly plants, animal waste, the root exudates and living organisms. The Organic Matter (OM) then undergoes biotransformation in soil: Biodegradation and eventually mineralization, which renders the carbon to the atmosphere as CO₂ (Victor 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 (Amundson and Biardeau, 2018). The biosphere plays an important role in the change since a low emission or sequestration rate cycle can cause a major change in carbon budget level (Yeasmin et al., 2020). To be able to predict climate change and find solutions to bearing or mitigate the problems predicted by the experts, it is important to quantify and better understand the dynamics of GHG compartments (Lefèvre et al., 2017). In the soils of some large ecosystems, such as African savannas or tropical forests, the storage of organic matter in the soil proceeds at the same rate as its degradation (Yeasmin et al., 2017). In agro-ecosystems, on the other hand, a balance can be upset by many factors, likely to favor the accumulation of organic matter, or conversely its mineralization. Rainfall and temperature play a major role (Lee et al., 2020). For example, low or too high humidity hinders the activity of decomposing organisms in soils, which therefore naturally accumulate more organic matter than others. Conversely, microbiological activities are multiplied by a factor of 2 to 3 when the temperature increases by 10°C (Lee et al., 2020). Climate change, which currently stimulates plant productivity (atmospheric CO₂ concentrations, temperature) and the mineralization of organic matter, has an impact that is difficult to assess on carbon storage. Finally, the physical and chemical nature of soils also reduces mineralization, through their ability to “protect” organic matter (Lee et al., 2020). Cashew agroecosystems are an important part of the plant community of the high altitude in the Sudano-Sahelian zone of Cameroon. They occupy a very important place for these values ecological, economic and social. Where he played for several roles user populations such as livestock feed in all periods including food scarcity period and supply of timber and firewood. According to our bibliographic investigations, no further work has hitherto targeted quantification of soil carbon stock of cashew agroecosystems. 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. The objective of this study is to assess the Soil organic carbon stock under different age ranges of cashew agroecosystems in the Sudano-Sahelian zone of Cameroon.

Materials and Methods

Study Area

The study was carried out in the north region of Cameroon. This region is located between 9°18’N to 8°10’N latitude and 13°23’E to 12°16’E longitude (Victor et al., 2019a). The northern region of Cameroon has a tropical climate of the Sudano-Sahelian type. 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 (Victor et al., 2020). The vegetation encountered is a shrubby Sudanian savannah with a clear and degraded savannah appearance (Victor et al., 2020). The fauna is rich and very diverse (Victor 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 Cameroon region.
Data Collection

Study Methods

Soil samples are taken from August to September 2018. In each 2000 m² survey, soil samples were taken in 0.25×0.25 m frames. These samples are taken at 0-10, 10-20 and 20-30 cm depth were collected in three age groups (0-10; 10-20; over 20 years old) of Cashew agroecosystems. The age of agroecosystems was determined by surveys of cashew growers. The survey was carried out among cashew producers. The targeted planters were those registered by the fruit production subdivision of IRAD in Garoua during the agricultural seasons from 2010 to 2018. The use of the report from IRAD in Garoua made it possible to get an idea of the situation in the areas. Strong cashew plantations as well as the soil types of the terroir. The choice of planters surveyed was made randomly among those with at least 1.5 hectares of agroecosystems. Thus, the investigation concerned 20 producers. The survey was carried out with one of the tools of the active method of participatory research and planning (the semi-structured interview). It took place at home and/or in the field at the convenience of each planter. The purpose of the survey was to obtain information on the age of cashew agroecosystems in the study area. 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 36 samples per site and then homogenized to obtain an aggregate sample. A total of 144 samples (3 sites ×3 depths ×4 replicates ×4 areas) for all four sites in the two regions studied were dug into the soil to a depth of 30 cm. These three groups were then weighed and oven-dried at a constant temperature of 70°C to a constant dry weight, which was measured. When the weight became constant, it was deduced that all the water contained in the material had completely evaporated and the resulting mass was that of the biomass. Once all samples were collected, they were taken for laboratory analysis.

Laboratory Methods

The laboratory method consists of determining, evaluating or measuring the physico-chemical parameters of the soils.

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 h, it was weighed again. The dry weight of the sample P divided by the sample Volume (V) gave the Bulk Density (BD) in g/cm³. It is calculated using the following formula \( \text{BD} = \frac{P}{V} \). 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 moisture content at 105°C which allows to estimate the water content. 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: \( H = (P_\text{gross air-dried})/(P_\text{net air-dried}) \times 100 \). Total Nitrogen was obtained by the (Kjeldahl, 1883) method after heat treatment of the sample with a mixture of sulphuric acid (\( \text{H}_2\text{SO}_4 \)) and salicylic acid (\( \text{C}_6\text{H}_4\text{(COOH)}\text{(OH)} \)). The granulometric analysis was carried out by the Robinson pipette method on air-dried soil samples sieved at 2 mm. The organic matter was previously destroyed by hydrogen peroxide attack. The soil was then dispersed by rotary agitation in flasks after the addition of potassium bicarbonate (\( \text{K}_2\text{Cr}_2\text{O}_7 \)) in an acid medium (\( \text{H}_2\text{SO}_4 \), \( \text{H}_2\text{O}_2 \)) which is an oxidation with potassium bicarbonate (\( \text{NaPO}_3 \)). The different particle size fractions were determined by pipetting for the clay and silt fractions and by sieving for the sand. The textural classes were found by using the FAO Textural Triangle, once the proportions of the different textural fractions were calculated. Soil organic carbon was determined by method of (Walkley and Black, 1934), which is an oxidation with potassium bicarbonate (\( \text{K}_2\text{Cr}_2\text{O}_7 \)) in an acid medium (\( \text{H}_2\text{SO}_4 \)). 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 Organic Carbon (SOCs) (tC/ha) = BD. (% OC). S. P (Victor et al., 2020) with BD: Bulk density in tones/m\(^3\); % OC: Organic carbon content of the soil; S: Area in m\(^2\); p: Depth m.

Data Analysis

The data were encoded in Excel 2007 software and then analyzed using Statgraphics 2007 and R software. Pearson correlation and Significance tests were performed using ANOVA and Duncan’s 5% test.

**Results**

**Soil Physical Characteristics**

The bulk density varies from 0.80±0.01 to 1.20±0.12 g/cm\(^3\) depending on the depth between the three age ranges of Cashew agroecosystems studied in the four subdivisions. Data analysis shows that there is no significant difference in bulk density between depths (\( P = 0.058>0.05 \)) on the one hand and between the three age groups of Cashew agroecosystems studied (\( P = 0.075>0.05 \)) on the other hand (Table 1).

Moisture content varies from 19.08±2.03 to 39.27±2.98% depending on depth between the three age ranges of agroecosystems studied in the four subdivisions. The highest moisture content values were recorded at depths of 20-30 cm. Data analysis shows that there is no significant difference in moisture content between depths (\( P = 0.195>0.05 \)) on the one hand and between the three age groups of Cashew agroecosystems studied (\( P = 0.112>0.05 \)) on the other hand (Table 2).

The granulometry distribution made it possible to distinguish 3 textural classes including sandy loam, sandy clay and silt soils. The soils studied are predominantly sandy. Data analysis for the textural fractions of the soils (Clay: \( P \)-value = 0.0268; Silt: \( P \)-value = 0.0000 and Sand: \( P \)-value = 0.0004) show that there is a variation in the textural composition of the soils at different depths between the three age groups of Cashew agroecosystems studied in the four subdivisions (Table 3).

| Subdivisions      | Depths (cm) | 0-10 years | 10-20 years | Over 20 years |
|-------------------|-------------|------------|-------------|--------------|
| Bénoué            | 0-10        | 0.86±0.05a | 1.12±0.11a  | 0.98±0.10a   |
|                   | 10-20       | 0.96±0.07a | 1.05±0.10a  | 1.13±0.08a   |
|                   | 20-30       | 0.94±0.03a | 1.06±0.10a  | 0.98±0.04a   |
|                   | Mean        | 0.92±0.05A | 1.07±0.03A  | 1.03±0.08A   |
| Faro              | 0-10        | 0.80±0.01a | 1.10±0.12a  | 0.81±0.01a   |
|                   | 10-20       | 0.85±0.02a | 0.80±0.01a  | 1.18±0.12a   |
|                   | 20-30       | 0.83±0.04a | 0.98±0.16a  | 0.96±0.11a   |
|                   | Mean        | 0.82±0.02A | 0.96±0.15A  | 0.98±0.18A   |
| Mayo-Loutii       | 0-10        | 0.94±0.11a | 0.91±0.14a  | 1.25±0.14a   |
|                   | 10-20       | 0.86±0.02a | 0.83±0.03a  | 0.98±0.13a   |
|                   | 20-30       | 0.89±0.01a | 0.86±0.10a  | 1.10±0.12a   |
|                   | Mean        | 0.89±0.04A | 0.86±0.04A  | 1.11±0.13A   |
| Mayo-Rey          | 0-10        | 1.15±0.13a | 1.20±0.12a  | 1.02±0.13a   |
|                   | 10-20       | 0.83±0.04a | 0.93±0.04a  | 0.90±0.06a   |
|                   | 20-30       | 0.88±0.03a | 0.98±0.01a  | 0.97±0.11a   |
|                   | Mean        | 0.95±0.17A | 1.03±0.14A  | 0.96±0.06A   |

Values assigned the same letter are not statistically different (\( p>0.05 \); Duncan’s test)
Table 2: Variation of moisture content as a function of depth under different Cashew agroecosystems

| Subdivisions   | Depths (cm) | 0-10 years | 10-20 years | Over 20 years |
|---------------|-------------|------------|-------------|---------------|
| Bénoué        | 0-10        | 20.32±2.08a| 23.21±2.44a| 33.67±2.86a   |
|               | 10-20       | 22.46±2.14a| 25.63±2.52a| 35.96±2.94a   |
|               | 20-30       | 25.34±2.18a| 28.86±2.86a| 39.27±2.98a   |
|               | Mean        | 22.85±2.13ab| 26.38±2.60b| 36.30±2.92A   |
| Faro          | 0-10        | 20.08±2.02a| 24.48±2.42a| 32.35±2.51a   |
|               | 10-20       | 20.15±2.08a| 24.80±2.47a| 33.93±2.67a   |
|               | 20-30       | 20.31±2.12a| 25.87±2.68a| 35.36±2.71a   |
|               | Mean        | 20.18±2.07a| 25.47±2.52b| 34.66±2.63A   |
| Mayo-Loutii   | 0-10        | 19.08±2.03a| 20.68±2.30a| 31.25±1.23a   |
|               | 10-20       | 19.90±2.08a| 23.58±2.38a| 32.18±1.15a   |
|               | 20-30       | 20.84±2.12a| 25.88±2.45a| 34.85±1.11a   |
|               | Mean        | 19.93±2.07a| 23.81±2.76ab| 34.43±2.18A   |
| Mayo-Rey      | 0-10        | 20.95±2.13a| 24.20±2.42a| 26.07±2.58a   |
|               | 10-20       | 21.78±2.20a| 26.27±2.54a| 28.65±2.74a   |
|               | 20-30       | 24.05±2.27a| 28.86±2.68a| 30.39±2.95a   |
|               | Mean        | 22.51±2.20ab| 26.60±2.54b| 28.37±6.92A   |

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

Table 3: Soil texture under the different Cashew agroecosystems

| Subdivisions   | Ages          | % sand     | % silt     | % clay     | Textural classes |
|---------------|---------------|------------|------------|------------|-----------------|
| Bénoué        | 0-10 years    | 52.01±5.42b| 27.46±7.74b| 20.52±6.73bc| Sandy clay      |
|               | 10-20 years   | 67.48±8.14bc| 20.15±6.54ab| 12.36±3.19a | Sandy loam      |
|               | 10-20 or 20+  | 63.99±7.29bc| 19.01±6.20a | 16.99±5.38b | Sandy loam      |
| Faro          | 0-10 years    | 60.11±7.30bc| 24.45±5.24ab| 22.09±9.53bc| Sandy clay      |
|               | 10-20 years   | 48.87±3.56a | 18.44±4.98a | 32.68±11.71c| Sandy clay      |
|               | 10-20 or 20+  | 71.86±8.24c | 17.83±4.67a | 10.30±3.72a | Sandy loam      |
| Mayo-Loutii   | 0-10 years    | 44.16±3.78a | 39.63±13.35c| 16.20±5.58b | Silty           |
|               | 10-20 years   | 48.08±3.07a | 27.96±7.80b | 23.95±8.44bc| Sandy clay      |
|               | 10-20 or 20+  | 56.17±5.98b | 31.86±9.64bc| 11.96±3.49a | Sandy loam      |
| Mayo-Rey      | 0-10 years    | 61.71±7.51bc| 22.33±6.08ab| 15.95±5.66b | Silty           |
|               | 10-20 years   | 56.68±6.05b | 30.03±9.08bc| 13.28±3.12a | Sandy loam      |
|               | 10-20 or 20+  | 56.49±5.58b | 27.57±7.42bc| 15.93±4.68ab| Sandy loam      |

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

Table 4: Variation of pH as a function of depth under different Cashew agroecosystems

| Subdivisions   | Depths (cm) | 0-10 years | 10-20 years | Over 20 years |
|---------------|-------------|------------|-------------|---------------|
| Bénoué        | 0-10        | 6.80±1.48a | 6.40±1.14a  | 5.67±1.06a    |
|               | 10-20       | 6.46±1.14a | 6.33±1.12a  | 5.57±1.04a    |
|               | 20-30       | 5.94±1.04a | 5.06±1.10a  | 5.08±1.00a    |
|               | Mean        | 6.40±1.22A | 5.93±1.12A  | 5.44±1.03A    |
| Faro          | 0-10        | 6.88±1.52a | 6.54±1.32a  | 6.41±1.21a    |
|               | 10-20       | 6.85±1.50a | 6.30±1.31a  | 5.93±1.17a    |
|               | 20-30       | 6.70±1.47a | 5.67±1.06a  | 5.36±1.11a    |
|               | Mean        | 6.81±1.49A | 6.16±1.23A  | 5.90±1.16A    |
| Mayo-Loutii   | 0-10        | 6.98±1.63a | 6.61±1.34a  | 6.25±1.23a    |
|               | 10-20       | 6.95±1.62a | 6.43±1.32a  | 6.18±1.15a    |
|               | 20-30       | 6.89±1.60a | 5.86±1.20a  | 5.34±1.11a    |
|               | Mean        | 6.94±1.61A | 6.30±1.28A  | 5.59±1.16A    |
| Mayo-Rey      | 0-10        | 6.95±1.63a | 6.20±1.12a  | 6.06±1.10a    |
|               | 10-20       | 6.78±1.60a | 6.03±1.04a  | 5.65±1.04a    |
|               | 20-30       | 6.67±1.57a | 5.86±1.01a  | 5.39±1.01a    |
|               | Mean        | 6.80±1.60A | 6.03±1.05A  | 5.70±1.05A    |

Values assigned the same letter are not statistically different (p>0.05; Duncan’s test)
**Soil Chemical Characteristics**

Soil reaction (pH) varies from 5.06±1.10-6.98±1.63 depending on the depth between the three age ranges of Cashew agroecosystems studied in the four subdivisions. The highest soil reaction (pH) values were recorded at depths of 0-10 cm. Data analysis shows that there is no significant difference in pH between depths (P = 0.075>0.05) on the one hand and between the three age groups of Cashew agroecosystems studied (P = 0.092>0.05) on the other hand (Table 4).

Total nitrogen levels ranged from 2.3±0.25-4.1±1.44 kg depending on the three age ranges of Cashew agroecosystems studied in the four subdivisions. Nitrogen levels are highest in the 0-10 year plots in all four regions studied. At only 5%, Data analysis (F = 1.19; P = 0.3443) revealed no significant difference in nitrogen content between the three age groups of Cashew agroecosystems studied and between the subdivisions (F = 0.40; P = 0.7544>0.05) (Table 5).

As for the mineralization of organic matter, it seems to be slower in the plots of more than 20 years old compared to the other plots of 0-10 years and 10-20 years old. At only 5%, Data analysis (F = 14.03; P = 0.0000) reveals a significant difference between the C/N ratios of the different plots studied. However, high values were recorded in plots older than 20 years and 10-20 years and different from those found for 0-10 year plots. Considering areas and ages, the 20-year-old Cashew agroecosystems in Bénoué subdivision had the highest C/N ratios. Data analysis did not show any significant difference in nitrogen content between subdivisions (F = 0.15; P = 0.9237>0.05) (Table 5).

| Subdivisions | Ages    | Total Nitrogen | C/N ratio |
|--------------|---------|----------------|-----------|
| Bénoué       | 0-10 years | 3.30±0.43ab   | 8.29±1.33bc |
|              | 10-20 years | 2.70±1.30ab   | 9.14±1.16def |
|              | Over 20 years | 2.30±0.25a    | 10.33±0.22f |
|              | Mean      | 2.76±0.50A    | 8.92±1.53A |
| Faro         | 0-10 years | 3.80±0.81ab   | 6.01±0.42ab |
|              | 10-20 years | 3.10±1.10ab   | 8.35±1.51cd |
|              | Over 20 years | 2.60±0.85ab   | 9.80±0.57ef |
|              | Mean      | 3.16±0.60A    | 8.05±1.91A |
| Mayo-Loutii  | 0-10 years | 4.10±1.44b    | 8.54±2.0ab  |
|              | 10-20 years | 3.10±0.95ab   | 8.31±0.58cd |
|              | Over 20 years | 2.50±0.43ab   | 10.12±0.36f |
|              | Mean      | 3.23±0.80A    | 7.99±2.30A  |
| Mayo-Rey     | 0-10 years | 3.30±0.75ab   | 8.56±0.59ab |
|              | 10-20 years | 2.80±0.72ab   | 8.70±1.12de |
|              | Over 20 years | 2.70±0.26a    | 9.75±1.16ef |
|              | Mean      | 2.93±0.32A    | 8.33±1.62A  |

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

| Subdivisions | Depths (cm) | 0-10 years | 10-20 years | Over 20 years |
|--------------|-------------|------------|-------------|---------------|
| Bénoué       | 0-10        | 0.31±0.04bc | 0.30±0.04ab | 0.38±0.07bc   |
|              | 10-20       | 0.20±0.03ab | 0.21±0.03ab | 0.27±0.05abc  |
|              | 20-30       | 0.20±0.03ab | 0.21±0.03ab | 0.25±0.04ab   |
|              | Mean        | 0.24±0.06A  | 0.23±0.03A  | 0.30±0.07A    |
| Faro         | 0-10        | 0.32±0.07bc | 0.26±0.05ab | 0.41±0.10c    |
|              | 10-20       | 0.21±0.04ab | 0.33±0.07bc | 0.21±0.04ab   |
|              | 20-30       | 0.20±0.03ab | 0.20±0.02a  | 0.20±0.03a    |
|              | Mean        | 0.24±0.06A  | 0.25±0.07A  | 0.27±0.08A    |
| Mayo-Loutii  | 0-10        | 0.26±0.05bc | 0.33±0.07bc | 0.25±0.04b    |
|              | 10-20       | 0.21±0.02a  | 0.27±0.06bc | 0.24±0.04b    |
|              | 20-30       | 0.20±0.02a  | 0.20±0.02a  | 0.21±0.03a    |
|              | Mean        | 0.21±0.04A  | 0.26±0.07A  | 0.23±0.020A   |
| Mayo-Rey     | 0-10        | 0.24±0.05ab | 0.23±0.05ab | 0.33±0.07bc   |
|              | 10-20       | 0.23±0.04ab | 0.26±0.06abc| 0.25±0.05ab   |
|              | 20-30       | 0.20±0.02a  | 0.21±0.04ab | 0.20±0.02a    |
|              | Mean        | 0.22±0.03A  | 0.24±0.04A  | 0.25±0.06A    |

Values assigned the same letter are not statistically different (p>0.05; Duncan’s test)
The mean SOC concentrations (%) ranges from 0.20±0.02-0.4±0.10%. The highest values of the mean SOC concentrations (%) were observed in the depth 0-10 cm. Data analysis does not reveal any significant difference in the mean SOC concentrations (%) between the depths on the one hand (P = 0.353>0.05) and between the three age groups of Cashew agroecosystems studied on the other, share (P = 0.408> 0.05) (Table 6).

Soil organic carbon stock varies from 16.45±0.73-37.04±2.32 tC/ha depending on depth between the three age ranges of Cashew agroecosystems studied in the four subdivisions. The highest values of soil organic carbon stocks were observed at depths of 0-10 cm. Cashew agroecosystems older than 20 years had the highest values of soil organic carbon stocks. Data analysis did not show a significant difference in soil organic carbon stocks between depths (P = 0.5178>0.05) and between the three age groups of Cashew agroecosystems studied (P = 0.4560>0.05) (Table 7).

**Relationship between Soil Organic Carbon Stock and Soil Pysico-Chemical Characteristics**

Soils with high C stock are sandy loamy textured soils (25.79±2.29 tC/ha or 36% of total soil C stock) followed by sandy clay soils (22.79±2.09 tC/ha or 34% of total soil C stock). On the other hand, soils containing large portions of silt are those with a low carbon stock (20.13±1.3 tC/ha or 30% of total soil carbon stock). Data analysis reveals a significant difference in soil C stock between textural classes (F = 6.11; P = 0.0185<0.05; Fig. 2).

**Table 7: Variation of soil organic carbon stock as a function of depth under different of Cashew agroecosystems**

| Subdivisions     | Depths (cm) | 0-10 years | 10-20 years | Over 20 years |
|------------------|-------------|------------|-------------|---------------|
| Bénoué           | 0-10        | 26.79±1.45bc| 29.18±1.78cd| 37.04±2.32de  |
|                  | 10-20       | 20.10±1.05ab| 22.52±1.26abc| 29.94±1.97cd  |
|                  | 20-30       | 19.20±1.02a | 21.77±1.20ab | 24.01±1.43bc  |
|                  | Mean        | 22.03±4.14A | 24.49±4.07A  | 30.33±6.52A   |
| Faro             | 0-10        | 25.76±1.43bc| 26.95±1.55bc | 33.04±2.12d   |
|                  | 10-20       | 17.68±0.88a | 26.08±1.50bc | 24.54±1.54bc  |
|                  | 20-30       | 16.93±0.77a | 18.42±0.96a  | 18.72±0.97a   |
|                  | Mean        | 20.12±4.89A | 23.81±4.69A  | 25.43±7.20A   |
| Mayo-Loutii      | 0-10        | 23.97±1.37bc| 29.57±1.89cd | 31.23±2.05de  |
|                  | 10-20       | 16.94±0.82a | 22.07±1.27abc| 23.07±1.32bc  |
|                  | 20-30       | 16.73±0.70a | 15.30±0.54a  | 22.90±1.28abc |
|                  | Mean        | 19.21±4.12A | 22.31±7.13A  | 25.73±4.76A   |
| Mayo-Rei         | 0-10        | 28.06±1.68cd| 27.36±1.65cd | 33.25±2.20cd  |
|                  | 10-20       | 18.67±0.98a | 24.55±1.54bc | 22.05±1.25abc |
|                  | 20-30       | 16.45±0.73a | 20.97±1.18ab | 18.23±0.93a   |
|                  | Mean        | 21.06±6.16A | 24.29±3.20A  | 24.51±7.80A   |

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

**Fig. 2:** Soil organic carbon stocks according to soil textural classes. Values assigned the same letter are not statistically different (p>0.05; Duncan’s test)
The results showed a positive and significant (P<0.05) correlation between soil organic C stock with bulk density, moisture content, C/N, SOC; negative and significant (P<0.05) with Soil pH, Total Nitrogen, but negative and non-significant (P>0.05) 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 8).

**Discussion**

The bulk density varies from 0.80±0.01-1.20±0.12 g/cm³ depending on the depth between the three age ranges of Cashew agroecosystems studied in the four subdivisions. This may be due to soil compaction which is variable across the three age groups of Cashew agroecosystems studied and also their soils are softened due to fine root mat, microbial and arthropod activities, leading to soil aeration. Cashew agroecosystems soils with high carbon stock are those with sandy loamy texture (25.79±2.29 tC/ha). This is normal since one of the main characteristics that influence the organic matter content and consequently the CO content of the soil is its texture (Dumoulin and Rollin, 2017). Cashew agroecosystems soils have a high OM decomposition rate 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. This ratio is higher the finer the texture and the more acidic the soil (Decoopman et al., 2013). The soil reaction (pH) varies from 5.06±1.10-6.98±1.63 depending on the depth between the three age groups of Cashew agroecosystems studied in the four subdivisions. These results are similar to those of (Bessah et al., 2016). Moisture content varies from 19.08±2.03-39.27±2.98% depending on the depths between the three age groups of Cashew agroecosystems studied in the four subdivisions. This would be influenced by the vegetation cover. The texture of these soils would 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 the pH, it is more acidic in forest soils. Indeed, tree growth involves taking ions from the soil by releasing others with identical electrical charges in order to maintain their electrical balance (Munguakonkwa, 2018). Since they need many cations rather than anions, their growth therefore releases many cations (often H+) into the soil, making it more acidic (Ranger, 2018). The texture of these forest soils will also justify their pH (Munguakonkwa, 2018). In fact, clay soils have a more acidic pH than sandy soils (Carrier, 2003).

The mean SOC concentrations (%) ranges from 0.20±0.02-0.41±0.10%. The highest values the mean SOC concentrations (%) were observed in the depth 0-10 cm. Therefore, the introduction of better land use management practices such as Sustainable Agricultural Land Management (SALM) practices will increase the stored SOC stocks (Verified Carbon Standards, 2014 in Bessah et al., 2016) The relevance of climate, soil type, vegetation, terrain and topography in the study area has no impact on the horizontal variability in SOC stocks due to it homogeneity (Bessah et al., 2016). Therefore, horizontal variability being insignificant in this study can also be attributed under different age ranges of cashew change. The top 0-10 cm depth recorded the highest SOC stocks under different age ranges of cashew agroecosystems but varied across land use types because land use management practices have a higher influence at top soil. Soil organic carbon stock varies from 16.45±0.73-37.04±2.32 tC/ha depending on depth between the three age ranges of cashew plantations studied in the four subdivisions. This result is within the range 9.80 and 49.63 tC/ha reported by (Bessah et al., 2016) in different land-use systems in Ghana. Vegetation types can alter soil carbon stocks due to several key factors, including litter fall and root turnover, soil chemistry, root exudates and microclimate (Victor et al., 2019a). Low carbon stocks in 0-10-year-old cashews 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).

### Table 8: Pearson correlation (R²) result of SOC stocks with other parameters

| Parameters         | 0-10 cm | 10-20 cm | 20-30 cm |
|--------------------|---------|----------|----------|
| Bulk density       | 0.895***| 0.903*** | 0.896*** |
| pH                 | -0.943***| -0.962***| -0.985***|
| Moisture content (%)| 0.983***| 0.981*** | 0.980*** |
| Total nitrogen (Kg)| -0.881** | -0.854***| -0.870***|
| C/N ratio (%)      | 0.754** | 0.610**  | 0.580*   |
| % OC               | 0.982***| 0.988*** | 0.708*** |
| % Sand             | 0.241ns | 0.213ns  | 0.234ns  |
| % Silt             | 0.229ns | 0.224ns  | 0.245ns  |
| % Clay             | 0.232ns | 0.230ns  | 0.068ns  |
| % Silt + Clay      | 0.282ns | 0.41ns   | 0.289ns  |

The coefficients at p<0.05 are significantly correlated; *: p≤0.05; **: p≤0.01; ***: p≤0.001 (test de Pearson); ns: non significative (p>0.05)
Results showed a positive and significant (P<0.05) correlation between soil organic C stock with bulk density, moisture content, C/N ratio, % OC; negative and significant (P<0.05) with Soil reaction pH, Total Nitrogen, but negative and non-significant (P>0.05) with % Sand, % Silt, % Clay, % Silt + Clay. Soil organic carbon stocks decreased with increasing depth in all three age groups of Cashew agroecosystems as reported in several results (Yan et al., 2012; Bessah et al., 2016; Victor et al., 2019a). The maximum depth of 0-10 cm recorded the highest soil organic carbon stock under all three age groups of Cashew agroecosystems (Bessah et al., 2016; Victor et al., 2019a; 2020).

Conclusion

This study gives us a better understanding of the soil organic carbon stock in the Cashew plantations studied. Soil is a non-renewable resource whose quality must therefore be preserved for its environmental functions. The soils under the plots of more than 20 cashew agroecosystems in Bénoué recorded higher SOCS values (36.30±2.92 tC/ha). Similarly, the SOCS decreased with soil depth in all three age groups of Cashew agroecosystems. The mean SOC concentrations (%) ranged from 0.20±0.02-0.41±0.10%. Soil organic carbon stock ranged from 16.45±0.73-37.04±2.32 tC/ha depending on depth between the three age ranges of Cashew agroecosystems studied in the four subdivisions. The Cashew agroecosystems soils with high C stock are those with sandy loamy texture (25.79±2.29 tC/ha). Results show that soil organic carbon stock is higher in Cashews over 20 years old. However, the evolution of COS stocks is more or less increasing as the cashew agroecosystems age. Of all the soil physico-chemical parameters measured, only bulk density, moisture content, C/N, % OC shows a strong and positive linear correlation with soil C stock among all the physico-chemical parameters measured. Soil physico-chemical parameters (texture, total nitrogen, C/N ratio, soil reaction (pH), soil bulk density, moisture content) also vary according to the three age groups of Cashew agroecosystems.

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Author’s Contributions

Awé Djongmo Victor: Designed, collected and checked the analyzed data; prepared the draft manuscript and supervised the final manuscript.

Noïlia Noumi Valery: Designed research plan and supervised this work.

Zapack Louis: Designed research plan and supervised this work.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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