Soil organic carbon (SOC) determination is very important in the assessment of agronomic potential of a soil. The objective of this study was to determine SOC contents and stock distribution with depth in relation to selected soil properties. Five types of soils, namely, Mollic Endoaquents, Oxyaquic Paleudalfs, Oxyaquic Udifluvents, and Mollic Udifluvents from a humid tropical plain and Typic Eutrudepts from an adjacent foot slope, were studied. The soils have all developed from fluvial sediments. Morphological and physicochemical characteristics of the soils were obtained using standard methods. Soil texture varied across the different sites and within soil profiles with textural classes of genetic horizons ranging from sandy loam to heavy clay. The soils are generally young soils under development as indicated by their high silt/clay ratios which ranged between 0.23 and 2.45. All the soils were generally acidic with pH-H$_2$O values ranging from 4.5 to 6.2. Exchangeable H$^+$ and Al$^{3+}$ ranged from 0.5 to 2.3 and 0.2 to 3.3 cmol·kg$^{-1}$, respectively. SOC contents are generally higher in surface horizons and decrease with depth. In general, SOC correlated significantly with bulk density (BD) ($r = -0.648$, $p < 0.01$), water holding capacity ($r = 0.589$, $p < 0.01$), exchangeable Al$^{3+}$ ($r = 0.707$, $p < 0.01$), and exchangeable H$^+$ ($r = 0.456$, $p < 0.05$). The correlation between SOC and exchangeable Al$^{3+}$ was strongest in the Mollic Endoaquents ($r = 0.931$, $p < 0.01$). SOC contents correlated significantly with Munsell soil color attributes, explaining between 40 and 57% of SOC variation. Total SOC stocks at a depth of 100 cm varied between 260.1 and 363.5 t·ha$^{-1}$, and the variation in SOC stocks across a profile appears to be controlled by genetic horizon depth, while land use type influences SOC stock variations across genetic surface horizons.

1. Introduction

Soil organic carbon (SOC) is a major indicator of soil quality and productivity and also a key driver of most soil processes and functions. It influences nutrient retention, microaggregate formation and soil structure, water retention/storage and infiltration, microbial activity, and pH buffering [1]. SOC is also fundamental to the role played by soil in providing ecosystem services such as regulating services (e.g., carbon sequestration, climate and greenhouse gas regulations), provisioning services (e.g., food, water, fuel, fiber), cultural services (e.g., ecotourism and recreation), and supporting services such as nutrient cycling [2]. Soils play a very important role in climate change adaptation and mitigation by regulating the global carbon cycle and have been identified as the largest pool of terrestrial organic carbon in the biosphere, with a carbon storage capacity surpassing that contained in plants and the atmosphere combined. According to Batjes [3], the top meter of the world’s soils stores about 2200 Pg of C, with about two-thirds (66%) of it stored as soil organic matter. This amount of C is almost thrice that found in the atmosphere. Under natural conditions, the storage of OC in soil is controlled by the balance of C inputs from plant production and outputs through decomposition [4]. However, anthropogenic disturbances, mainly agricultural activities and forest clearance for fuel and timber, greatly contribute to the emission of large quantities of the stored carbon into the atmosphere [5]. On the other hand, improved cultivation practices such as addition of biochar [6], incorporation of crop residues [7, 8],...
and conservation tillage [9–11] can significantly increase soil carbon sequestration. Apart from the influence of human activities, many biophysical factors influence SOC storage and distribution patterns (Table 1).

In general, SOC exists in three distinct fractions, namely, passive, intermediate, and active [35]. The active and intermediate fractions are found in the top 1 meter of soil and are often collectively known as labile SOC [36]. The SOC found in this fraction is biologically available and more susceptible to changes at the soil surface [37]. The labile fraction is the smallest pool of SOC and is estimated at 250–350 Pg [36]. This fraction originates from fresh organic residues and living organisms, and its turnover ranges from days to few decades. On the other hand, the passive or more stable fraction of SOC (chemically stable in the form of humus) is often found concentrated below 1 m and is not readily accessible to microorganisms for decomposition [36].

This stable fraction includes fine-sized organic matter that is physically protected (e.g., clay mineral-protected or contained within soil aggregates) or chemically persistent (humus) in soil. The turnover period of this fraction ranges from centuries to millennia [35]. The subsoil contains the largest pool of SOC and is the least likely to be influenced by changes in management practice and different environmental conditions than top soil [50].

Monitoring and quantifying SOC contents and stocks across landscape units and over time are crucial for the assessment of spatial and temporal variations in SOC pools and fluxes. More specifically, SOC stock estimates are important for global climate change predictions [51]. This is also very useful in understanding changes in soil fertility/productivity levels, soil deterioration/amelioration, water quality, environmental degradation, etc., hence necessitating the adoption of sustainable soil management practices for enhancing SOC storage and increased ecosystem services. However, data availability for assessing environmental changes is a major constraint, especially in most developing countries of tropical environments. This is mainly associated with a lack of adequate research facilities and too much generalization about tropical soils [52], confirming the assertion that much is still unknown about the soil resources in tropical environments compared to those in temperate regions [53]. Inventories of SOC stocks at local scales are useful and can readily be used to assist most countries in achieving the goals of the United Nations Framework Convention on Climate Change (UNFCCC).

The nonexistence of a national SOC database for Cameroon [54] could limit its ability to access funds from the Clean Development Mechanism (CDM) as proposed under article 12 of the Kyoto Protocol of the UNFCCC. The CDM allows developing countries to establish emission reduction (or emission removal) projects that can earn certified emission reductions (CERs), each equivalent to 1 t of CO₂ that can then be traded and sold, and used by industrialized countries to meet some of their emission reduction targets under the Kyoto Protocol. Thus, estimation of SOC stocks at local scales constitutes baselines for large-scale inventories that would significantly improve the accuracy of national SOC databases. In Cameroon, a dearth of information exists on the C sequestration potential of plain soils. Like in most areas worldwide, plains in Cameroon constitute areas of intensive agricultural production that would significantly impact on the soil carbon storage potential. The objective of this study was to determine SOC contents and their distribution with depth in relation to selected soil physicochemical and morphological properties in five dominant soil types within the Mbo plain.

2. Materials and Methods

2.1. Location and Characteristics of the Study Area. The Mbo plain is located within longitudes 9° 45′E and 10° 07′E and latitudes 5° 07′N and 5° 25′N. The plain has an average altitude of 720 m above sea level and extends over a surface area of about 30,000 ha. It lies between the Bamileké plateau (1400–2000 m) in the north and east, the dorsal part of the Ekome Mountain (about 1800 m) in the west, and the Manengouba volcanic massif (2400 m) in the south (Figure 1). Geomorphologically, the Mbo plain is an ancient lake depression on a granite-gneissic base, resulting from deposits of the first volcanic eruptions of Mount Manengouba [55]. A lava flow of this eruption blocked the plain in the north, favoring the creation of a lake. This was followed by the draining of this lake by the Nkam River, causing its disappearance [55]. The northern and eastern parts of the Mbo plain are dominated by the Bamileké plateau comprised of granite and gneiss, with very steep escarpments. The southern part of the plain is dominated by basalt lava flow from Mount Manengouba which descends progressively towards the plain [56]. Between these borders is a vast depression occupied by swamps containing a dense hydrographic network of many streams and the Nkam River.

The vegetation distribution in the Mbo plain is conditioned by hydrologic and edaphic factors [57]. The remaining semideciduous forests are mostly found at the peripheries of the plain, on the flanks of the mountains which dominate it. It is on glacial that most of the forest in the Mbo plain has been destroyed for the establishment of farmlands and plantations. On relatively nutrient-poor zones, Hyparrhenia sp. and some teak (Tectona grandis) plantations abound. On well-drained areas gallery forests having considerably reduced in size following clearing for the establishment of farmlands and settlement. Vast areas within the Mbo plain are either permanently or seasonally flooded, especially in depressions. These depressions are covered by fern (Pteridium aquilinum), raffia (Raphia farinifera), oil palm (Elaeis guineensis), and screw pine (Pandanus sp.). The dominant farming system in the Mbo plain consists of intensive cultivation of both annual and perennial crops for both subsistence and commercial purposes. The dominant crops cultivated include cassava (Manihot
esculenta), cocoyam (Colocasia esculenta), sweet potatoes (Ipomoea batatas), maize (Zea mays), plantain and banana (Musa spp.), cocoa (Theobroma cacao), coffee (Coffea arabica), ginger (Zingiber officinale), and a wide variety of vegetables and fruits. Vast untapped arable lands in the Santchou and Mbomi areas of this plain have high potential for developing large-scale rice production.

Following the Köppen–Geiger classification, the climate in the Mbo plain is described as Am (tropical monsoon climate), occasionally known as a tropical wet climate or tropical monsoon or trade-wind littoral climate. Mean monthly temperatures are generally above 18°C in every month of the year, with two distinct seasons prevailing—the rainy (wet) season which runs from March to October and the dry season which runs from November to February (Figure 2). The difference in rainfall between the driest and wettest month is about 420mm. Mean annual temperature is about 23.6°C with an annual temperature variation of 2.7°C, and mean annual rainfall is about 2500mm. The hottest month is March, with a mean monthly temperature of 24.8°C, while the coldest month is August with a mean monthly temperature of 22.1°C. Average relative humidity is high throughout the year (>70%) and highest in the months of July and August (>90%). Winds are relatively high during the months of December and January.

2.2. Field Methods and Laboratory Analyses. A survey was conducted on five soil profiles representing the major land use/cover types and geomorphological features (Table 2, Figure 3). Major environmental characteristics, physiography, and soil profiles were described in the field following standard procedures [60]. Bulk soil samples from each genetic horizon were collected and stored in polythene bags. In addition, undisturbed core samples for bulk density determination were collected from each genetic horizon using stainless steel Kopecky rings.

Soil samples from the field were air-dried and crushed using a porcelain mortar and pestle and then sieved through a 2 mm sieve to remove coarse fragments, roots, and plant residues. The <2 mm soil fraction was used for the various physicochemical analyses. Soil pH was measured in distilled deionized water, 1 M KCl, and 0.01 M CaCl₂ in a 1:2.5 soil-to-solution ratio as described by Kome et al. [61]. Soil electrical conductivity was determined in a 1:5 soil-to-solution ratio using distilled deionized water and a conductivity meter as described by Kome et al. [61]. Soil organic carbon was determined using the Walkley–Black method [62]. Bulk density was calculated as the oven dry (105°C) mass of undisturbed core sample per volume. Particle size analysis was conducted using the hydrometer method as described by Bouyoucos [63]. Effective dispersal of the soil samples was achieved using a 2.5N solution of sodium hexametaphosphate. The relative proportions of sand, silt, and clay were used to calculate the sand/silt and silt/clay ratios, while the clay ratio was calculated using the formula

\[
\text{clay ratio} = \frac{\% \text{ clay}}{\% \text{ sand} + \% \text{ silt}}
\]

Water holding capacity (WHC) was determined following procedures described by Pansu and Gautheyrou [64].

2.3. Estimation of SOC Stocks. Soil organic carbon stocks per horizon were estimated using the genetic horizon equation [65] as follows:

\[
\text{SOC stock (t ha}^{-1}) = \left( \frac{\text{mg SOC}}{\text{g soil}} \right) \times \left( \frac{\text{g soil}}{\text{cm}^3 \text{ soil}} \right) \times \left( \frac{\text{cm}}{\text{T}} \right) \times \left( \frac{t}{10^8 \text{ mg}} \right) \times \left( 10^8 \text{ cm}^2 \text{ ha}^{-1} \right) \times \left( 1 - \delta_{2 \text{mm}}, \% \right).
\]

Total SOC stock per soil profile to a depth of 1 m was estimated by summing the SOC stocks per genetic horizon:

---

**Table 1: Major biophysical factors influencing SOC storage and distribution patterns.**

| Biophysical factors                          | References |
|---------------------------------------------|------------|
| Vegetation type                             | [12]; [13]; [14] |
| Soil biodiversity                            | [15] |
| Soil texture                                 | [13]; [16]; [17]; [18] |
| Soil pH                                      | [19]; [20]; [21] |
| Soil microaggregates                          | [22]; [23]; [24] |
| Temperature (sensitivity of SOC decomposition)| [25] |
| Climate                                      | [12]; [17]; [26]; [27]; [28] |
| Precipitation                                | [29] |
| Leaching of carbonates                        | [30]; [31] |
| Mineralogy                                   | [21]; [32]; [33]; [34] |
| Soil erosion                                 | [1]; [38]; [39]; [40] |
| Topography                                   | [12]; [40]; [41]; [42] |
| Soil depth                                   | [3]; [26]; [43]; [44] |
| Soil type (reference group)                  | [12]; [27] |
| Vegetation fires                             | [45]; [46]; [47] |
| Accelerated SOM decomposition caused by global warming | [31]; [48]; [49] |

---
\[
\text{total SOC stock (t ha}^{-1}) = \sum_i^n \left( \frac{\text{mg SOC}}{\text{g soil}} \right) \times \left( \frac{\text{g soil}}{\text{cm}^3 \text{ soil}} \right) \\
\times \left( \frac{\text{cm}}{T} \right) \times \left( \frac{\text{t}}{10^8 \text{ mg}} \right) \\
\times \left( \frac{10^8 \text{ cm}^2}{\text{ha}} \right) \times (1 - \delta_{2mm})
\]

where mg SOC g soil}^{-1} \text{ is SOC concentration, g soil cm soil}^{-3} \text{ is bulk density, cm is soil horizon thickness, and } \delta_{2mm} \% \text{ is fractional percentage (%) of } >2 \text{ mm coarse fragments by volume.}

Genetic soil horizons of entire soil profiles were used to estimate SOC stocks rather than soil control sections because the latter has been proven to overestimate SOC stocks [44].

2.4. Statistical Analyses. The relationships between soil properties were established using correlation and regression analyses. Statistical analyses were performed using Microsoft Excel 2007 and SPSS (Version 23) for Windows.
3. Results and Discussion

3.1. Morphological Properties

3.1.1. Soil Color. Morphological characteristics of the various soils (Table 3) show a wide range of colors in terms of value and chroma. Profile 1, with a cambic (Bw) horizon, has a moist hue of 10YR throughout the profile except in the Bw2 horizon where the moist hue is 2.5YR. The Bw2 horizon also has a moist hue of 5Y as inclusions. From the Ap to the Bw1 horizon, the colors change from dark brown through brown to yellowish brown. The heterogeneity in terms of color observed in the Bw2 horizon (grayish red, pale orange, dull yellow orange, and bright yellowish brown) is associated with the influence of chemical weathering on the parent material, while that of the surface horizon is mainly due to organic matter. The Bw3 and Cr horizons are dominated by a bright yellowish brown color. In the dry state, profile 1 has hues of 5YR, 7.5YR, and 10YR from surface to subsurface horizons, with generally higher values and lower chroma compared to the corresponding horizon colors in moist state.

Profile 2 has granular structure in the Ap horizon and subangular blocky in subsurface horizons. The granular structure of surface horizons is associated with bioturbation by soil fauna and plant roots, especially where biological activity is high. Some parts of the Bw3 horizon of profile 1 show a blocky structure, associated with its expanding clay contents. The consistence (moist) varies from friable in the A and AB horizons to firm in the cambic (Bw) horizons and then to weak in Cr horizons where the soil is very friable. Consistence (wet) is very sticky and very plastic in horizons with blocky structures, and nonsticky and nonplastic in horizons with granular structures. Occurrence of krotovinas in the first five horizons of this profile and their dominance in the Bw3 horizon indicate transportation and accumulation of material (mainly organic matter) from one horizon to another. Weathered quartz veins traverse from Bw2 to Cr2 horizons in a NW to SE direction, with pressure faces of roots visible throughout the profile. Profile 2 structure is granular in the Ah horizon; blocky in the E, Bt, and Btg horizons; and granular in the C horizons. The consistence ranges from hard to very hard (dry) and friable to firm (moist). Field observations reveal that the soil surface of this profile cracks during the dry season forming medium (1-2 cm) to wide (3–5 cm) cracks, giving rise to a very hard structure, a kind similar to that of Vertisols which makes tillage with common tools such as hoes difficult. This cracking phenomenon is apparently associated with the presence of swelling-type clay minerals formed through neosynthesis processes, favored by the prevailing environmental conditions (in a depositional basin environment). Profile 3 has structure and consistence in the moist and dry states similar to those of profile 2. However, the consistence (wet) of profile 3, mostly very sticky and very plastic, is associated with the high contents of its swelling clays. Structure and consistence in profiles 4 and 5 do not show any regular pattern from surface to subsurface horizons. Here texture is more determinant as sandy horizons (mostly BC and C) generally have a granular, weak, or a subangular blocky structure that easily fragments in the moist...
3.2. Physical Properties

3.2.1. Bulk Density.

Bulk density (BD) distribution within the different profiles shows erratic functions (Figure 4), associated with the differences in the nature and composition of the sedimentary parent materials and the variation in SOC contents. A negative and significant correlation exists between BD and SOC ($r = -0.648$, $p < 0.01$), indicating that BD increases with decrease in SOC contents. The highest BDs (>1.30 Mg m$^{-3}$) occur in subsurface horizons of profiles 1 (Bw horizon), profile 2 (Btg and Ch horizons), and profile 5 (BCt and Cg horizons), while the lowest BD (0.66 Mg m$^{-3}$) occurs in the surface (Ah) horizon of profile 2 resulting from its high organic matter contents. All the other profiles have surface bulk density of about 1 Mg m$^{-3}$.

3.2.2. Particle Size Distribution (Texture). Soil texture varies across the different sites and within some profiles (Table 4, Figure 4). Profile 1 has textures ranging from clayey to loam. Profile 2 with textures ranging from heavy clay to loam.

**Table 2:** Description of study sites and classification of representative soil profiles.

| Site characteristics       | Bamia series                      | Santchou series                     | Lelem series                      | Ntengie series                     | Bamengwi series                     |
|----------------------------|-----------------------------------|-------------------------------------|-----------------------------------|-----------------------------------|-------------------------------------|
| Geographical coordinates   | Lat: 05° 17′ 51.5" N, Long: 09° 55′ 00.9″ E | Lat: 05° 16′ 23.5" N, Long: 09° 58′ 26.0″ E | Lat: 05° 12′ 02.5" N, Long: 09° 59′ 54.0″ E | Lat: 05° 21′ 59.1″ N, Long: 10° 00′ 27.9″ E | Lat: 05° 15′ 03.09″ N, Long: 10° 05′ 22.7″ E |
| Land use/vegetation        | Intensely cultivated farmland dominated by mixed crops, including cocoa, cocoyam, plantain, oil palm, and maize | Uncultivated patch (relics) of gallery forest, having wild palms, lianas, mixed trees, shrubs, and grass | Cultivated farmland with mixed crops, including maize, sweet potato, cowpea, okra, huckleberry, and pepper | Cultivated farmland with mixed perennial crops, including oil palm, cocoa, coffee, banana, and plantain |

**Soil management**

**- Tillage type**

Minimum tillage

**- Fertilization**

Occasional fertilization

Foot slope, 2–5 % (strongly sloping), medium-gradient hill on straight concave slope, good external drainage and moderate internal drainage. Piedmont of the escarpment which limits the plain

Plain, 0 % (flat terrain), poor external drainage and moderate internal drainage

Plain, almost flat terrain (0-1%), good external drainage and moderate internal drainage

Plain, flat terrain (0-1%), good external drainage and moderate internal drainage

Physiography

Foot slope, 751 m asl

No signs of erosion

Parent material

Granite

Alluvial sediments (for subsurface soil) and organic matter (for surface layer)

Alluvial sediments

Alluvial sediments

Alluvial sediments

Relief/elevation

Foot slope

Signs of slight geologic erosion with presence of gentle rills on soil surface

No signs of erosion

Erosion

No signs of erosion

Soil moisture regime

Udic

Udic/aquic

Udic/aquic

Udic/aquic

Udic/aquic

Soil temperature regime

Isohyperthermic

Isohyperthermic

Isohyperthermic

Isohyperthermic

Isohyperthermic

Soil classification:

IUSS working group WRB, [58]

Eutric Cambisol

Abruptic Gleysol (Humic)

Endoclayic Luvisol (Gleyic)

Humi-Dystric Fluvisol

Gleyi-Humic Fluvisol (Eutric)

Soil classification:

Soil survey staff [59]

Typic Eutrudepts

Mollic Endoaquents

Oxyaquic Paleudalfs

Oxyaquic Udifluvents

Mollic Udifluvents

state. The consistence of the Cg horizons of profiles 4 and 5 was either loose or friable (moist) and nonplastic (wet).
indicates that it originates from different parent materials. The surface Ah horizon has a loamy texture with a high silt/clay ratio of 1.23, while the underlying 2Bt/E horizon has an abrupt texture of heavy clay with a very low silt/clay ratio of 0.23 indicating that it has formed from a more advanced weathered material [66] compared to the Ah horizon, apparently dominantly formed from the accumulation of OM originating from the prevailing grassland vegetation. The high sand/silt ratios and very high sand contents (>46%) at >90 cm depths are indicative of differential sedimentation following Stokes’ law. Profile 3 with clayey textural class throughout the profile is in agreement with the advanced weathering stage of the profile as indicated by the low silt/clay ratio (≤0.76) corroborated by the development of argillic (Bt) horizons. The textures in profile 4 range from clay loam in the surface horizon to sandy clay loam in the AB, Cg, and 2AB horizons, and clay loam in the 2Btg and 2BC horizons. Stratigraphic breaks indicative of different provenance of the parent materials are indicated by sand contents, sand/silt ratios, and BD. Textures in profile 5 vary from loam through sandy loam to clay loam.

This profile is the one developed from the most varied parent material as indicated by erratic depth functions of sand, sand/silt ratios, and silt/clay ratios. The very high silt/clay ratios (>1.4) in all (except the Bct) horizons of this soil indicate that the deposited materials in the different horizons are of recent age with a low degree of weathering. There was a significant and negative correlation between sand and clay content (r = −0.855, p < 0.01) and also between sand and clay ratio (r = −0.784, p < 0.01), confirming the classical relationship existing between sand and clay. The sand/silt ratio had a similar trend to sand content with a strong and significant correlation observed between them (r = 0.855, p < 0.01). This shows that the sand/silt ratio can be used as an index in qualifying weathering trends in these soils, whereby high sand/silt ratios indicate low weathering intensities (less developed soils), while low sand/silt ratios indicate materials with high weathering intensities (more developed soils) [67]. On the other hand, the silt/clay ratio gives an indication of the degree of weathering of parent materials [66–68], whereby soils with silt/clay ratios <0.15 are reported to have developed from highly weathered parent materials, while those with ratios >0.15 are reported to have developed from young parent materials with low degree of weathering [67]. Silt/clay ratios in the soils studied ranged between 0.23 and 2.45 for all horizons, indicating that they have developed from parent materials still at an initial weathering stage. However, the sharp differences in silt/clay ratio observed between different horizons of a particular soil profile are indicative of differences in the provenance and nature (composition) of the parent materials.

3.3. Chemical Characteristics

3.3.1. Soil Acidity and Electrical Conductivity. All the soils studied were generally acidic and have a net negative charge on the soil exchange complex. The trend in pH values is pH-H₂O > pH-CaCl₂ > pH-KCl (Table 5). Profiles 2 and 3 are the most acidic with pH-H₂O values ranging between 4.5 and 5.0, followed by profiles 1 and 4 with pH-H₂O values of 5.2 to 5.8, and lastly by profile 5 with pH-H₂O values 5.7 and 6.4. Profiles 1 and 2 do not exhibit any depth functions. However, in profiles 3, 4, and 5, pH values generally increase from surface to subsurface horizons. Exchangeable Al³⁺ and H⁺ concentrations are highest in profile 2 followed by profile 3. Profile 2, with the humic Ah horizon, is strongly acidic with a pH-H₂O value of 4.8 and exchangeable Al³⁺ of 3.3 cmol/kg⁻¹, consistent with the high solubility of Al³⁺ at low pH values.

The electrical conductivity of all the soils is very low (<0.05 dSm⁻¹), indicating that these soils are nonsaline. The highest EC value was observed in surface horizons of profile 4, apparently associated with addition of salts from fertilizers inputs.
Table 3: Morphological characteristics of the soils.

| Horizon | Depth (cm) | Color | Structure | Consistence | Voids | Roots and biological features | Nodules/concretions | Boundary characteristics |
|---------|------------|-------|-----------|-------------|-------|-------------------------------|---------------------|------------------------|
|         |            |       |           |             |       |                               |                     |                        |
| **Profile 1. Bamia series** |            |       |           |             |       |                               |                     |                        |
| Ap      | 0–10       | 10YR 3/3 | 5YR 5/2  | GR SHA    | FRF   | VST and VPL                   | Few F and M        | Common F, M, C, E, and T |
|         |            |       |           |             |       |                               |                     |VF quartz grains        |
|         |            |       |           |             |       |                               |                     | C and S                |
| AB      | 10–24      | 10YR 4/6 | 7.5YR 6/6 | SB HA     | FRF   | VST and VPL                   | Few F and M        | Few F and M, E, and T  |
|         |            |       |           |             |       |                               |                     |VF quartz grains        |
|         |            |       |           |             |       |                               |                     | D and S                |
| Bw₁     | 24–42      | 10YR 5/6 | 7.5YR 6/4 | SB HA     | FI    | VST and VPL                   | Few M               | Few M and C, T         |
|         |            |       |           |             |       |                               |                     |F quartz grains         |
|         |            |       |           |             |       |                               |                     | D and S                |
| Bw₂     | 42–72/90   | 10YR 6/4 | 7.5YR 6/4 | SB HA     | FI    | ST and PL                     | Few C               | Very few C             |
|         |            |       |           |             |       |                               |                     | M quartz grains        |
|         |            |       |           |             |       |                               |                     | D and W                |
| Bw₃     | 72/90–102  | 10YR 6/8 | 7.5YR 7/2 | SB GR, BL | HA FI | SST and SPL                   | Few C               | Very few C             |
|         |            |       |           |             |       |                               |                     | M quartz grains        |
|         |            |       |           |             |       |                               |                     | D and W                |
| Cr₁     | 102–157    | 10YR 8/3 | 10YR 8/3 | SB GR     | VHA WE | VST and VPL                   | Few C               | Very few C             |
|         |            |       |           |             |       |                               |                     | Common M               |
|         |            |       |           |             |       |                               |                     | D and S                |
| Cr₂     | 157–215    | 10YR 8/3 | 10YR 8/3 | SB GR     | VHA WE | VST and VPL                   | Few C               | Very few C             |
|         |            |       |           |             |       |                               |                     | Common M               |
|         |            |       |           |             |       |                               |                     | D and S                |
| **Profile 2. Santchou series** |            |       |           |             |       |                               |                     |                        |
| Ah      | 0–12       | 7.5YR 2/1 | 10YR 2/3 | GR HA     | FR    | SST and NPL                   | Many F and M        | Common F, M, C, E, and T |
|         |            |       |           |             |       |                               |                     | N                      |
| 2B/E    | 12–38      | 7.5YR 6/1 | 10YR 6/3 | BL VHA    | FI    | VST and VPL                   | Few C               | Very few C             |
|         |            |       |           |             |       |                               |                     |VF quartz grains        |
|         |            |       |           |             |       |                               |                     | C and S                |
| 2E/Bt   | 38–58      | 7.5YR 5/6 | 10YR 7/3 | BL VHA    | FI    | VST and VPL                   | Few C               | Very few F             |
|         |            |       |           |             |       |                               |                     |VF quartz grains        |
|         |            |       |           |             |       |                               |                     | D and S                |
| 2Btg₂   | 58–90      | 7.5YR 6/2 | 10YR 6/3 | BL VHA    | FI    | VST and VPL                   | N                   | Very few F             |
|         |            |       |           |             |       |                               |                     | N                      |
| 2Btg₃   | 90–115     | 7.5YR 5/6 | 10YR 7/2 | BL VHA    | FI    | VST and VPL                   | N                   | Very few F             |
|         |            |       |           |             |       |                               |                     | N                      |
| 2C₁     | 115–167    | 7.5YR 4/3 | 10YR 7/6 | GR HA     | WE FR | SST and SPL                   | N                   | N                      |
|         |            |       |           |             |       |                               |                     | D and S                |
| 2C₂     | 167–205    | 7.5YR 6/2 | 10YR 7/6 | GR HA     | WE FR | SST and SPL                   | N                   | N                      |
|         |            |       |           |             |       |                               |                     | D and S                |
| Horizon | Depth (cm) | Color | Structure | Consistence | Wet | Voids | Roots and biological features | Nodules/concretions | Boundary characteristics |
|---------|------------|-------|-----------|-------------|-----|-------|--------------------------------|-------------------|--------------------------|
| **Profile 3. Lelem series** | | | | | | | | | |
| A | 0–18 | 7.5YR 4/4 | 10YR 5/4 | SB → GR | HA | FR | ST and PL | VST and VPL | Many F, M and C | Many F, M, C, T | N | C and S |
| Bt1 | 18–43 | 7.5YR 5/4 | 10YR 5/6 | SB → GR | VHA | FI | Common F, M and C | Many F, M, C, T | N | D and S |
| Bt2 | 43–73 | 7.5YR 5/4 | 10YR 5/6 | AB | VHA | FI | Common F, M and C | Few F, M, C, T | N | D and S |
| Btg | 73–118/ 134 | 7.5YR 5/4 | (Matrix) 7.5YR 3/3 (mottles) 7.5YR 6/2 (matrix) 10YR 6/4 (mottles) | SB | VHA | FI | VST and VPL | Few M and C | Very few F, M, C, T | N | D and W |
| BCtg | 118/ 134–175 | 7.5YR 3/2 | (mottles) 7.5YR 5/6 | (mottles) | SB → GR | VHA | FI | VST and VPL | Few M and C | Very few F, M, C, T | N | D and W |
| **Profile 4. Ntengie series** | | | | | | | | | |
| Ap | 0–27 | 7.5YR 3/3 | 10YR 4/4 | SB | VHA | FI | SST and SPL | SST and SPL | Many F, M and C | Many F, M, T | N | G and S |
| AB | 27–50 | 7.5YR 5/6 | 10YR 4/4 | SB → GR | HA | FI | Many F and M | Many F, M, C, T | N | D and S |
| Cg | 50–82 | 7.5YR 4/6 | (matrix) 7.5YR 5/8 | (mottles) | GR | LO | LO | NST and NPL | Many F and M | Few F and M | N | C and S |
| 2AB | 82–116 | 7.5YR 4/3 | 10YR 3/4 | SB | HA | FI | ST and PL | ST and PL | Few M and C | Few F and M | N | D and S |
| 2Btg | 116–160 | 7.5YR 5/4 | 10YR 4/6 | AB | HA | FI | Few M and C | Few F and M | N | C and S |
| 2BC | 160–210 | 7.5YR 5/6 | 10YR 5/6 | SB → GR | HA | FI | Few M and C | Few F and M | N | D and S |
| **Profile 5. Bamengwi series** | | | | | | | | | |
| Ap | 0–25 | 7.5YR 3/2 | 10YR 5/4 | SB → GR | VHA | FR | ST and PL | ST and PL | Many F, M and C | Many F, M, T and few E | N | G and S |
| AB | 25–44 | 7.5YR 5/6 | 10YR 6/4 | GR | SSH | FR | Many F and M | Many F, M, C, T, and few B | N | G and S |
| Bct | 41–66 | 7.5YR 4/4 | 10YR 6/3 | BL | VHA | FI | Many F and M | Few F and M | N | C and W |
| 2Cg1 | 66–102 | 10YR 7/6 | (matrix) 7.5YR 7/8 | (mottles) 7.5YR 6/3 | (matrix) 7.5YR 6/8 | (mottles) 10YR 6/4 | (mottles) 10YR 7/8 | (mottles) | WE SB | SHA | LO | NST and NPL | Few M and C | Few F and M | N | C and W |
| 3Cg2 | 102–134 | 7.5YR 6/6 | (mottles) | SB → GR | VHA | FR | ST and PL | Few M and C | Few F and M | N | D and S |
### Table 3: Continued.

| Horizon | Depth (cm) | Color | Structure | Consistence | Voids | Roots and biological features | Nodules/concretions | Boundary characteristics |
|---------|------------|-------|-----------|-------------|-------|-------------------------------|---------------------|-------------------------|
| 4Cg3    | 134–162    | 7.5YR 6/4 (matrix) | 10YR 7/3 (mottles) | SB → GR SSH FR | Few M and C | Few F and M | N | D and S |
|         |            | 7.5YR 5/8 (mottles) | 10YR 7/8 (mottles) |             |       |          |          |            |
| 5Cg4    | 162–205    | 7.5YR 6/2 (matrix) | 10YR 7/8 (mottles) | SB → GR VHA FR | Very few F | Few F and M | N | D and S |

Note. BL blocky, SB subangular blocky, GR granular, AB angular blocky, SB → GR subangular blocky parting to granular, SHA slightly hard, HA hard, VHA very hard, SSH soft to slightly hard, WE weak, FR friable, FI firm, FRF friable to firm, LO loose, ST sticky, SST lightly sticky, PL plastic, SPL slightly plastic, VST very sticky, VPL very plastic, NST nonsticky, NPL nonplastic. For boundary, G gradual (5–15 cm), A abrupt, (0–2 cm), C clear (2–5 cm), D diffuse (>15 cm), S smooth, W wavy. For roots and biological features, F few, M many, C common (for abundance of roots), E earthworm channels, B burrows, T ant channels. For voids, F fine, M medium, C coarse, N none. For nodules and concretions, N none, F few, VF very few. Source: FAO [60].

![Figure 4: Continued.](image-url)
3.3.2. Soil Organic Carbon Distribution. Soil organic carbon contents were generally higher in surface horizons and decreased with depth (Table 5, Figure 4). The surface Ah horizon of profile 2 has the highest SOC content of 5.74% contributed by the prevailing grassland vegetation. Generally, OM accumulation in the Ah horizon is largely dependent on the influx of litter-layer decomposition products and in situ accumulation of root decomposition products [69]. All the profiles recorded the lowest SOC contents in the C horizons, except for the Bt1 horizon of profile 3. Despite the dominance of clay and clay loam textures in the surface horizons, SOC did not show any significant relationship with texture. The variation of SOC stocks with depth is consistent with the stratifications observed with depth in the soils derived from alluvium as corroborated by BD, sand, and sand/silt depth functions. The SOC stocks at a depth of 1 m were highest in profile 2 (under grassland vegetation) with an estimated value of 363.5 t·ha⁻¹, while the lowest values were recorded in profile 4 (farmland) (260.1 t·ha⁻¹) and profile 5 (264.0 t·ha⁻¹). Both soils with very high porosities and high sand contents would favor faster mineralization of OM, compared to the more rich clay soils [70], though increased tillage activities play a complementary role. Reports indicate that grassland soils store significant amounts of SOC and about 34% of the global terrestrial carbon [28].
3.3.3. Relationship between SOC and Physicochemical Properties. Correlation analysis indicates that SOC and SOc stocks have significant relationships with some physical and chemical soil properties (Table 6, Figure 5). A negative and significant correlation exists between SOC and BD ($r = -0.648, p < 0.01$), reflecting the classical relationship that exists between them and further confirming that BD across the soil profiles is largely influenced by OM content. The positive and significant relationship between SOC and WHC ($r = 0.589, p < 0.01$) indicates that increase in SOM increases the soil’s ability to retain water. However, there was a negative and significant relationship between SOC stocks and WHC ($r = -0.451, p < 0.01$) and also a negative and significant relationship between BD and WHC ($r = -0.636, p < 0.01$). A multiple linear regression equation between WHC as the dependent variable with SOC and BD as independent variables was established as follows: $\text{WHC} = 44.51 + 1.47 \times \text{SOC} - 11.96 \times \text{BD} (R^2 = 0.460, p < 0.01)$. This indicates that SOC and BD can explain 46% of the variance associated with WHC, and thus this equation could be used to estimate WHC from SOC and BD data. Soil organic carbon had a positive and significant correlation with exchangeable Al$^{3+}$ ($r = 0.707, p < 0.01$) and exchangeable H$^+$ ($r = 0.456, p < 0.05$) when the data were pooled together. The relationship between SOC and exchangeable acidity would only be valid for profiles 2, 3, and 4 with pH-H$_2$O values $< 5.5$. However, the relationship between SOC and exchangeable Al$^{3+}$ was strongest in profile 2 ($r = 0.931, p < 0.01$). A linear regression between SOC and exchangeable Al$^{3+}$ in profile 2 gave an $R^2$ value of 0.867 (Figure 6), indicating that SOC can be conveniently estimated from exchangeable Al$^{3+}$ in this soil type.

| Horizon | Depth (cm) | BD (Mg m$^{-3}$) | Porosity (%) | WHC (%) | Sand (%) | Silt (%) | Clay (%) | Clay ratio | Sand/silt ratio | Silt/clay ratio | Textural class* |
|---------|------------|------------------|--------------|---------|----------|---------|---------|-----------|-----------------|----------------|-----------------|
| **Profile 1. Bamia series** | | | | | | | | | | | |
| Ap | 0–10 | 1.07 | 59.62 | 40.22 | 33 | 35 | 32 | 0.47 | 0.94 | 1.09 | CL |
| AB | 10–24 | 1.16 | 56.23 | 40.07 | 30 | 23 | 47 | 0.89 | 1.30 | 0.49 | C |
| Bw1 | 24–42 | 1.20 | 54.72 | 40.40 | 27 | 27 | 46 | 0.85 | 1.00 | 0.59 | C |
| Bw2 | 42–72/90 | 1.32 | 50.19 | 30.74 | 37 | 27 | 36 | 0.56 | 1.37 | 0.75 | CL |
| Bw3 | 72/90–102 | 1.25 | 52.83 | 30.46 | 36 | 29 | 35 | 0.54 | 1.24 | 0.83 | CL |
| Cr1 | 102–157 | 1.01 | 61.89 | 30.97 | 50 | 23 | 27 | 0.37 | 2.17 | 0.85 | SCL |
| Cr2 | 157–215 | 1.23 | 53.58 | 30.54 | 46 | 35 | 19 | 0.23 | 1.31 | 1.84 | L |
| **Profile 2. Santchou series** | | | | | | | | | | | |
| Ah | 0–12 | 0.66 | 75.09 | 49.02 | 42 | 32 | 26 | 0.35 | 1.31 | 1.23 | L |
| 2Bt/E | 12–38 | 1.13 | 57.34 | 31.85 | 20 | 15 | 65 | 1.86 | 1.33 | 0.23 | HC |
| 2E/Bt | 38–58 | 1.11 | 58.11 | 32.21 | 24 | 16 | 60 | 1.50 | 1.50 | 0.27 | C |
| 2Btg2 | 58–90 | 1.15 | 56.60 | 34.90 | 17 | 17 | 66 | 1.94 | 1.00 | 0.26 | HC |
| 2Btg3 | 90–115 | 1.30 | 50.94 | 36.55 | 46 | 15 | 39 | 0.64 | 3.07 | 0.38 | SC |
| 2CI | 115–167 | 1.34 | 49.43 | 33.48 | 56 | 14 | 31 | 0.44 | 4.00 | 0.45 | SCL |
| 2C2 | 167–215 | 1.40 | 47.17 | 28.02 | 65 | 19 | 16 | 0.19 | 3.42 | 1.19 | SL |
| **Profile 3. Lelem series** | | | | | | | | | | | |
| A | 0–18 | 1.15 | 56.60 | 31.75 | 28 | 31 | 41 | 0.69 | 0.90 | 0.76 | C |
| Bt1 | 18–43 | 1.19 | 55.09 | 35.15 | 19 | 35 | 46 | 0.86 | 0.54 | 0.76 | C |
| Bt2 | 43–73 | 1.19 | 55.09 | 31.22 | 15 | 25 | 60 | 1.50 | 0.60 | 0.41 | C |
| Btg | 73–118/134 | 1.09 | 58.87 | 31.40 | 16 | 33 | 51 | 1.04 | 0.48 | 0.65 | C |
| Bctg | 118/134–175 | 1.14 | 56.98 | 29.98 | 15 | 26 | 59 | 1.44 | 0.58 | 0.44 | C |
| **Profile 4. Ntengie series** | | | | | | | | | | | |
| Ap | 0–27 | 0.92 | 65.28 | 35.68 | 39 | 33 | 28 | 0.39 | 1.18 | 1.18 | CL |
| AB | 27–50 | 0.78 | 70.57 | 42.64 | 54 | 20 | 26 | 0.35 | 2.70 | 0.77 | SCL |
| Cg | 50–82 | 1.11 | 58.11 | 35.05 | 64 | 12 | 24 | 0.32 | 5.33 | 0.50 | SCL |
| 2AB | 82–116 | 0.80 | 69.81 | 38.88 | 47 | 24 | 29 | 0.41 | 1.96 | 0.83 | SCL |
| 2Btg | 116–160 | 1.11 | 58.11 | 27.12 | 33 | 32 | 35 | 0.54 | 1.03 | 0.91 | CL |
| 2BC | 160–210 | 1.18 | 55.47 | 36.34 | 36 | 26 | 38 | 0.61 | 1.38 | 0.68 | CL |
| **Profile 5. Bamengwi series** | | | | | | | | | | | |
| Ap | 0–25 | 1.03 | 61.13 | 35.01 | 29 | 44 | 27 | 0.37 | 0.66 | 1.63 | CL |
| AB | 25–44 | 1.01 | 61.89 | 37.61 | 38 | 40 | 22 | 0.28 | 0.95 | 1.82 | L |
| Bct | 41–66 | 1.30 | 50.94 | 28.06 | 43 | 24 | 33 | 0.49 | 1.79 | 0.73 | CL |
| 2Cg1 | 66–102 | 1.30 | 50.94 | 32.82 | 59 | 29 | 12 | 0.14 | 2.03 | 2.42 | SL |
| 3Cg2 | 102–134 | 1.31 | 50.57 | 33.08 | 28 | 42 | 29 | 0.41 | 0.67 | 1.45 | CL |
| 4Cg3 | 134–162 | 1.32 | 50.19 | 33.74 | 64 | 24 | 12 | 0.14 | 2.67 | 2.00 | SL |
| 5Cg4 | 162–205 | 1.29 | 51.32 | 35.16 | 62 | 27 | 11 | 0.12 | 2.30 | 2.45 | SL |

*Textural class according to FAO [60]. WHC: water holding capacity, CL: clay loam, C: clay, SCL: sandy clay loam, L: loam, HC: heavy clay, SC: sandy clay, and SL: sandy loam.

Table 4: Physical properties of the soils.
relationship shows that exchangeable Al$^{3+}$ forms strong complexes with OM as best observed in the humic surface horizon of profile 2. Low pH soils such as those in this study are reported to have Al$^{3+}$-OM complexation as well as Al$^{3+}$ toxicity as the main OM stabilization mechanisms [20, 71]. In view of the role played by soil pH in controlling soil OM stabilization mechanisms, Clarholm and Skyllberg [20] indicate that soil pH values between 6.2 and 6.8 constitute a "window of opportunity," whereby SOM stabilization controlled by cations such as Al is not strong. Variations in soil pH in these soils would thus be attributed to both SOM type and clay content, given that a positive correlation exists between clay content and exchangeable H$^+$ ($r$ = 0.708, $p < 0.01$). The positive relationship observed between OC and exchangeable H$^+$ indicates that soil acidity increases with increase in SOM content. Given that H$^+$ is part of the humus carboxyl (-COOH) under acidic conditions, when the soil's acidity decreases, there is a greater tendency for the H$^+$ to be removed from humic acids and to react with hydroxyl (OH$^-$) to form water. The carboxyl groups on the humus develop negative charges as the positively charged H$^+$ is removed. When the soil pH is increased, the release of H from carboxyl groups helps to buffer the increase in pH and at the same time creates the CEC (negative charge). Thus, when OM increases, the soil recovers its natural buffer capacity, thereby increasing soil pH and hence increasing the soil's capacity to retain cations.

In general, there was no significant relationship between SOC and texture. Observations by Hassink [16] indicate that SOC contents varied considerably between soils with similar clay and silt contents. However, the latter found highly significant positive correlations between the clay and silt

| Horizon | Depth (cm) | pH-H$_2$O | pH-CaCl$_2$ | pH-KCl | EC (dSm$^{-1}$) | SOC (%) | SOC stocks (t ha$^{-1}$) | SOC stocks at 100 cm depth (t ha$^{-1}$) | Al$^{3+}$ (cmol·kg$^{-1}$) | H$^+$ (cmol·kg$^{-1}$) |
|---------|------------|------------|-------------|--------|----------------|---------|--------------------------|--------------------------------|----------------|----------------|

| **Profile 1. Bamia series** | | | | | | | | | | |
| Ap | 0–10 | 5.8 | 5.1 | 4.5 | 0.03 | 2.53 | 27.1 | – | – |
| AB | 10–24 | 5.6 | 4.8 | 4.2 | 0.01 | 2.53 | 41.1 | – | – |
| Bw$_1$ | 24–42 | 5.5 | 4.4 | 4.0 | 0.01 | 2.40 | 51.8 | – | – |
| Bw$_2$ | 42–72/90 | 5.4 | 4.4 | 4.0 | 0.01 | 2.50 | 128.7 | 0.9 | 0.0 |
| Bw$_3$ | 72/90–102 | 5.5 | 4.6 | 4.1 | 0.01 | 2.0 | 45.0 | 295.7 | – | – |
| Cr$_1$ | 102–157 | 5.6 | 4.5 | 4.1 | 0.01 | 2.0 | 111.1 | – | – |
| Cr$_2$ | 157–215 | 5.6 | 4.5 | 4.2 | 0.01 | 1.87 | 133.4 | – | – |

| **Profile 2. Santchou series** | | | | | | | | | | |
| Ah | 0–12 | 4.8 | 4.3 | 3.8 | 0.02 | 5.74 | 45.5 | 3.3 | 2.2 |
| 2Bt/E | 12–38 | 4.8 | 4.5 | 4.1 | 0.01 | 3.91 | 114.9 | 1.8 | 2.3 |
| 2E/Bt | 38–58 | 4.5 | 4.1 | 3.6 | 0.01 | 2.78 | 61.7 | 0.5 | 2.0 |
| 2Btg2 | 58–90 | 4.5 | 4.0 | 3.8 | 0.01 | 3.00 | 110.4 | 1.7 | 1.4 |
| 2Btg3 | 90–115 | 5.0 | 4.8 | 4.4 | 0.01 | 2.39 | 77.7 | 363.5 | 0.8 | 0.7 |
| 2Cl | 115–167 | 4.7 | 4.2 | 4.0 | 0.00 | 1.35 | 94.1 | 0.6 | 0.5 |
| 2C2 | 167–205 | 4.9 | 4.5 | 4.2 | 0.00 | 1.30 | 69.2 | 0.5 | 0.0 |

| **Profile 3. Lelem series** | | | | | | | | | | |
| A | 0–18 | 4.5 | 4.0 | 3.5 | 0.01 | 3.26 | 67.5 | 0.7 | 1.6 |
| Bt1 | 18–43 | 4.7 | 4.1 | 3.6 | 0.01 | 3.35 | 99.7 | 0.5 | 1.5 |
| Bt2 | 43–73 | 4.8 | 4.3 | 3.5 | 0.00 | 1.17 | 41.8 | 0.6 | 1.9 |
| Btg | 73–118/134 | 4.8 | 4.4 | 3.6 | 0.00 | 2.22 | 128.2 | 274.2 | 0.7 | 1.4 |
| Btg2 | 118/134–175 | 4.9 | 4.3 | 3.8 | 0.01 | 1.57 | 87.7 | 0.4 | 1.3 |

| **Profile 4. Ntengie series** | | | | | | | | | | |
| Ap | 0–27 | 5.3 | 5.0 | 4.3 | 0.04 | 3.00 | 74.5 | 0.2 | 0.0 |
| AB | 27–50 | 5.2 | 4.7 | 4.3 | 0.02 | 3.65 | 65.5 | 0.2 | 0.0 |
| Cg | 50–82 | 5.2 | 4.8 | 4.3 | 0.02 | 2.48 | 88.1 | 0.2 | 0.0 |
| 2AB | 82–116 | 5.4 | 5.0 | 4.8 | 0.02 | 2.22 | 60.4 | 260.1 | 0.3 | 0.0 |
| 2Btg | 116–160 | 5.5 | 5.1 | 4.6 | 0.02 | 1.57 | 76.7 | 0.3 | 0.0 |
| 2BC | 160–210 | 5.5 | 4.9 | 4.4 | 0.02 | 1.17 | 69.0 | 0.3 | 0.0 |

| **Profile 5. Bamengwi series** | | | | | | | | | | |
| Ap | 0–25 | 5.7 | 5.1 | 4.2 | 0.02 | 3.39 | 87.3 | – | – |
| AB | 25–44 | 6.0 | 5.6 | 4.6 | 0.01 | 2.61 | 50.1 | – | – |
| Bct | 41–66 | 6.0 | 5.3 | 4.5 | 0.01 | 2.22 | 72.2 | – | – |
| 2Cg1 | 66–102 | 6.2 | 5.8 | 4.7 | 0.01 | 1.30 | 60.8 | 264.0 | – | – |
| 3Cg2 | 102–134 | 6.1 | 5.6 | 4.9 | 0.01 | 2.09 | 87.6 | – | – |
| 4Cg3 | 134–162 | 6.4 | 5.8 | 5.1 | 0.01 | 2.11 | 78.0 | – | – |
| 5Cg4 | 162–205 | 6.2 | 5.8 | 4.9 | 0.01 | 1.08 | 59.9 | – | – |
Table 6: Correlation matrix of the soil properties.

|        | Clay   | Sand   | Silt  | Sand/silt | Silt/clay | Clay ratio | WHC   | BD    | SOC   | pH-H₂O | pH-CaCl₂ | pH-KCl | Exch. Al³⁺ | Exch. H⁺ |
|--------|--------|--------|-------|-----------|-----------|------------|-------|-------|-------|--------|---------|--------|------------|---------|
| Clay   | 1      |        |       |           |           |            |       |       |       |        |         |        |            |         |
| Sand   | -0.855**| 1      |       |           |           |            |       |       |       |        |         |        |            |         |
| Silt   | -0.262 | -0.277 | 1     |           |           |            |       |       |       |        |         |        |            |         |
| Sand/silt | -0.814** | 0.855**| -0.086| 1         |           |            |       |       |       |        |         |        |            |         |
| Silt/clay | -0.801** | 0.505**| 0.543**| 0.764**  | 1         |            |       |       |       |        |         |        |            |         |
| Clay ratio | 0.963**| -0.784**| -0.327| -0.664**  | -0.692** | 1         |       |       |       |        |         |        |            |         |
| WHC    | -0.115 | 0.076  | 0.072 | -0.019    | 0.045     | -0.149    | 1     |       |       |        |         |        |            |         |
| BD     | -0.031 | 0.116  | -0.160| 0.247     | 0.095     | 0.003     | -0.636**| 1     |       |        |         |        |            |         |
| SOC    | 0.172  | -0.230 | 0.108 | -0.317    | -0.171   | 0.152     | 0.589**| -0.648**| 1     |        |         |        |            |         |
| pH-H₂O | -0.667**| 0.442* | 0.407*| 0.555**   | 0.730**   | -0.634**  | 0.010 | 0.191 | -0.333| 1     |         |        |            |         |
| pH-CaCl₂| -0.658**| 0.474**| 0.329| 0.614**   | 0.738**   | -0.591**  | 0.036 | 0.130 | -0.295| 0.902**| 1        |        |            |         |
| pH-KCl | -0.683**| 0.603**| 0.135| 0.624**   | 0.617**   | -0.618**  | 0.067 | 0.124 | -0.305| 0.843**| 0.912**  | 1      |            |         |
| Exch. Al³⁺| 0.173  | -0.177 | 0.039 | -0.148    | 0.057     | 0.238     | 0.480* | -0.301| 0.707**| -0.381 | -0.376   | -0.291 | 1         |         |
| Exch. H⁺ | 0.708**| -0.682**| 0.067| -0.603**  | -0.390    | 0.702**   | 0.073 | -0.089| 0.456*| -0.788**| -0.700** | -0.762**| 0.606**   | 1       |

**Correlation is significant at the 0.01 level (2-tailed); *correlation is significant at the 0.05 level (2-tailed). SOCs: SOC stock.
contents of some soils and the amounts of C associated with these fractions; in some cases, lower amounts of C were associated with the fine-sized particles. These observations indicate that the amount of SOC that can be bound or adsorbed is a function of the type of clay minerals present (phyllosilicates versus sesquioxides) and their corresponding specific surface area and charge characteristics which impact on this behaviour [32]. With the diversity of soil types observed in this study, having a wide range of silt/clay ratios, apparently these soils exhibit wide mineralogical differences with corresponding differences in their binding capacity with SOC. Thus, other factors, apart from soil texture, such as land use type and management (C additions) would likely be responsible for SOC storage [72, 73].

3.3.4. Relationship between SOC and Soil Color. Soil organic carbon contents had a negative correlation with soil value and/or soil chroma in both moist and dry states (Table 7). These results indicate that, based on the correlation coefficients, Munsell soil color attributes explain between 40 and 57% of the variance associated with SOM. This has important implications for application as Zelenak [74] reported that soil color could successfully be used to estimate SOM.
contents as it could explain approximately 50% of the variance associated with SOM. Pretorius et al. [75] reported that, based on a high coefficient of determination ($R^2 = 0.91$) for coastal plain soils of South Africa, when the sum of dry and wet value and chroma values is 9 or more, carbon content will be ≤4.79%. From the results of this study, soil color attributes, notably value and chroma, can be conveniently used to estimate organic matter contents, where cost constraints are an important factor in laboratory analyses.

### 4. Conclusion

In this study, SOC contents and stocks in five major soils types of the Mbo plain were estimated, and SOC distribution along soil profiles presents erratic depth functions. SOC had significant correlations with exchangeable Al$^{3+}$ and H$^+$, bulk density, water holding capacity, and Munsell soil color attributes. The correlations indicate that soil SOC can be conveniently estimated from exchangeable Al$^{3+}$ in the Mollic Endoaquents. The results obtained in this study serve as baseline information that can be used for monitoring soil quality changes in this humid tropical environment, especially in areas subjected to intensive agricultural practices. Future studies to investigate detailed biological, chemical, and mineralogical properties are recommended in order to acquire more knowledge on soils of the Mbo plain. Additionally, detailed studies on the spatial variability of SOC are recommended in order to guide decision-making on sustainable soil management in the plain.

### Data Availability

The data used in this paper are available from the corresponding author upon request.

### Conflicts of Interest

The authors declare no conflicts of interest.

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### Table 7: Correlation matrix between SOC and Munsell color attributes.

|         | VM    | CM    | VM + CM | VD    | CD    | VD + CD | SOC |
|---------|-------|-------|---------|-------|-------|---------|-----|
| VM      | 1     |       |         |       |       |         |     |
| CM      | 0.338 | 1     |         |       |       |         |     |
| VM + CM | 0.670**| 0.925**| 1       |       |       |         |     |
| VD      | 0.659**| 0.425*| 0.601**| 1     |       |         |     |
| CD      | −0.125| −0.052| −0.091  | −0.471**| 1     |         |     |
| VD + CD | 0.545**| 0.379*| 0.519**| 0.564**| 0.463**| 1       |     |
| SOC     | −0.573**| −0.402*| −0.549**| −0.515**| −0.021 | −0.537**| 1   |

*Correlation is significant at the 0.01 level (2-tailed); **correlation is significant at the 0.05 level (2-tailed). VM: value (moist), CM: chroma (moist), VM + CM: value (moist) + chroma (moist), VD: value (dry), CD: chroma (dry), VD + CD: value (dry) + chroma (dry).
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