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Research Article

# Robust Variation in the Potentials of Tanzanian Soils under Sisal Plantation to Stabilize Organic Carbon and Nitrogen: A Case of Handeni District

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## ABSTRACT

Understanding the impacts of tillage erosion on Soil Organic Carbon (SOC) and Nitrogen (N) fractions is essential for targeted soil conservation in cropland areas. SOC and N play significant role in the global Carbon (C) and N cycles. Establishing SOC and N stock is a good step towards implementing the "4 per 1000" (4p1000) initiative which was launched at the COP21 conference in Paris aiming to slow down the rising levels of atmospheric carbon dioxide ($CO_2$). Thus, it is essential to understand how much SOC and N are stored in the soil and if possible to determine how long these nutrients persist belowground. Previous studies indicate that the storage of SOC and N strongly affected the interaction of climate and minerals. However, most of these results have not consistently considered the cropland soils (sisal plantation) as specific ecosystem. In attempting this study, we sampled the sisal plantation of Handeni District because the area partly represents the grassland of Tanzania. Sixteen soil sampling points were established within ten hectares and they involved two soil depths (i.e. 0-20 cm and 20-40 cm) and two locations (lowland and upland). The results exhibit that there have been significant variations of SOC and N accumulations under the two soil depths and locations. In the lowland areas, SOC was 1.3 and 0.45 MgC $ha^{-1}$ for the depths 0–20 cm and 20-40 cm, respectively. Besides, in upland areas, SOC was 0.60 and 0.34 MgC $ha^{-1}$ for the depths 0–20 cm and 20-40 cm, respectively. Similarly, the total N was significantly higher 2.12 Mg (0-20 cm) in lowland than in upland 1.80 Mg (0-20 cm). The same pattern happened in the depth (20-40 cm) where lowland had 1.40 Mg and upland had 1.16 Mg. These insights in cropland soils allow us to infer that the alterations of SOC and N are significantly influenced by climate change and minerals. Biologically, the microbial activity and microbial biomass correlate with SOC and N. This means, different agro-ecological zones of the country can have different SOC and N storages.

**Keywords:** Climate change; Cropland; Nitrogen; Sisal plantation; Soil organic carbon; Tanzania

## INTRODUCTION

Various demographic studies project that by 2050 the planet Earth will be having over nine billion people. This will automatically increase the global demand of agricultural products and other environmental services [1,2]. Practically, there will be increased demands for better ecosystems that can support life [1]. Among the significant entities that build proper ecosystems include soil and climate change [3]. This is why Soil Organic Carbon (SOC) and Nitrogen (N) dynamics have formed an important research topic over the last several decades, resulting in estimates of global C and N stocks [4-6].

Besides population growth, climate change affects soil nutrients and thus, exacerbating environmental and societal challenges [7]. In addition, anthropogenic activities such as agriculture have adverse impacts to ecosystems in most developing countries [8,9]. Therefore, it is essential to understand how much SOC and N are stored in the soil and how long they persist belowground and their dynamism.

As scientists, understanding the mechanisms and dynamics of SOC and N is necessary for the international frame for mitigation of climate change, which has been a crucial issue since the 1980s, sparking numerous discussions in many charters of international agreement [9]. Hence, climate situation and population are among the serious challenges that will extremely exacerbate the

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life system of planet Earth [3,10,11].

Globally, there are substantial differences in SOC and N accumulation among land uses [12,13]. It has been confirmed that in soils under intensive agricultural and horticultural management, the accumulation of SOC and N is larger than in low intensity grazed rangelands and small-holder arable cropping [14]. The latter is more pronounced in most tropical Africa [4,6]. In most cases, there have been high inconsistencies in undertaking studies on SOC and N accumulation based on spatial and anthropogenic differences.

A number of scientific studies have been established on SOC and N in the tropics and semi-arid region [15,16]. However, most of these studies have paid less attention on sisal planted areas. As a result, there has been increased demand for assessing SOC and N in these areas. To bridge this gap, empirical studies have certainly advanced our understanding of SOC and N dynamics following soil amendments in various grassland ecosystems [17].

While most studies have revealed the significance of intensive agriculture in the accumulation of SOC and N, Purwanto et al. [9] revealed that inappropriate implementation of intensive agricultural systems that does not consider the balance between SOC and N input and output can negatively affect soil fertility mainly by decreasing SOC and N, changing the composition of C and N owing to the loss of soil organic matter through erosion and leaching, and therefore, causing soil degradation.

So far, other findings indicate that many soils of southern Africa are severely C and N deficient [18,19]. However, this deficiency offers larger opportunity for C sequestration in sisal planted areas of the tropics. This verdict further underpinned that grassland is among the vulnerable ecosystems to C and N dynamics. This is amplified by the combustion of plant biomass, volatilizing C and N from organic matter before it can be decomposed and integrated into soils [12,20,21]. Besides, it is also confirmed that a reduced microbial activity and microbial biomass per area, together with a higher soil C stock and C:N ratio suggested a lower microbial decomposition in cropland areas [22].

Since SOC and N are among the main indicators of soil quality and health, it is imperative to enable their availability and sustainability in various ecosystems [23]. Studies from grassland Africa and elsewhere confirm the importance of SOC and N nutrition in crop yields and environmental conservation [5,24]. Similarly, SOC and N stock are imperative for C sequestration especially in implementing the "4 per 1000" (4p1000) initiative which was launched at the COP21 conference in Paris aiming to slow down the rising levels of atmospheric $CO_2$. Thus, sustainable land management for maintenance of SOC and N dynamics should be locally and globally developed and adopted for a more sustainable agricultural system and climate sequestrations [14,25].

On that basis, this study is quite important because soil provides several ecosystem services including

- A medium for plant and agricultural production through maintenance of soil fertility,
- A filter for toxins and pollutants,
- A regulator of the hydrologic cycle, and
- A potential mitigation of climate change through C sequestration as established by Winowiecki et al. and Jiang et al. [26].

Although various studies are linking SOC and N content to mineralogy, vegetation and climate, but there is less data on the cropland ecosystem especially in tropical Africa [14,27,28]. Another gap remains how different landscape under different land uses including interactions with land degradation processes scale is rigorously included in the design and sampling. Therefore, the objective of this study was to assess the status of SOC and N stocks in cropland ecosystems under sisal plantation of Tanzania in order to determine their storage and influence on the provision of environmental services.

## MATERIALS AND METHODS

### Study area

Handeni District is one of the 11 districts of Tanga Region in Tanzania. The district covers an area of 6,534 $km^2$ (2,523 sq m). Geographically, the district is bordered to the west by the Kilindi District and the Handeni Urban District, to the north by the Korogwe District, to the east by the Pangani District, and to the south by the Pwani Region. According to the 2012 census, the population had increased to: 276,646. The estimated current (in 2022) population of the district is about 300,000.

The study site is located in Segera village at latitude (5°17'59" S) and longitude (38°32'59" E), with the altitude of 468 meters (1,535 feet) above sea level (a.s.l.) in Handeni District, Tanzania.

Based on Köppen climate type, the area experiences a tropical monsoon climate with an average temperature of 28°C and total annual rainfall ranging from 750 to 1200 mm. The detail on the design and sampling procedures is described in the soil sampling section. The areas under permanent sisal cropping for more than twenty years were sampled for this study [12]. This biophysical scenario was preempted at the time of profile description and sampling according to Food and Agricultural Organization (FAO) guidelines [29].

### Soil sampling

This study was carried out between June and July 2022 in Segera village. Soil sampling procedures considered the scientific guidelines for soil description [29]. For precise sampling, we established two locations and in each location two sites were determined as seen in Table 1. The main locations were upland and lowland while the sites were denoted as A and B.

**Table 1:** Soil sampling per sites

| Locations | Depth (cm) | No. of samples (Site one-A) | No. of samples (Site two-B) |
|---|---|---|---|
| Lowland areas | 0-20 | 16 | 16 |
| | 20-40 | 16 | 16 |
| Upland areas | 0-20 | 16 | 16 |
| | 20-40 | 16 | 16 |
| Total | | 64 | 64 = 128 |

**Note:** Field Soil Sampling

In total, 128 soil cores in both locations and sites were sampled. Apart from establishing locations and site in the sampling, we also established two depths. We therefore, established sixteen soil sampling points within ten hectares. The specific soil depths involved 0–20 cm and 20–40 cm and for each depth we selected randomly the field to establish four soil ditches (W×L×D = 40×50×40 cm) as seen in Table 1. We established these depths because we know that SOC and N can vary with climate, soil type, land use, management practices, vegetation type, texture, classification, horizons, aspect, surface slope, elevation change and soil depth. The determined depths were adequate to represent cropland ecosystem under sisal plantation.

In each established ditch, we sampled four soil cores using a 150 mL volumetric soil sampler (6 cm diameter and 5.3 cm height). Volume-specific samples at 5 cm increments were collected in each soil profile without mixing horizons. This is why the current study considered the level of disturbance and depth in the soil sampling. The soil samples were subsequently analyzed at the Department of Soil Sciences and Geological Studies at Sokoine University of Agriculture.

## Laboratory analysis

Soil analyses were done in July 2022 in the Department of Soil Sciences and Geological Studies at Sokoine University of Agriculture. The Walkley-Black Method was used for SOC analyses [30]. The analysis considered the locations (lowland and upland) and depths (0-20 cm and 20-40 cm). The current procedure considers the Revised Legend [31] and clusters the corresponding soil profile data into two (0-20 cm and 20-40 cm). The analysis was also done according to FAO guidelines [29].

SOC was analyzed using Walkley-Black Method while soil N was analyzed using modified Kjeldahl procedure while available Phosphorus (P) was extracted using Bray 1 method and determined by spectrophotometric procedure [32]. Alongside, other soil parameters including physical and chemical aspects were analyzed as supporting elements. These include; pH, Electrical Conductivity (EC) and Exchange Capacity (CEC) of various elements.

For an individual profile with k layers, the equation of Batjes [33] was used to calculate the amount of SOC in the whole soil profile:

$$SOC_d = \sum_{i=1}^{k} SOC_i = \sum_{i=1}^{k} \rho_i \times P_i \times D_i \times (1 - S_i) \text{ .......... (1)}$$

$$\mathrm{SOC_i} = \rho_i \times \mathrm{P_i} \times \mathrm{D_i} \times (1 - \mathrm{S_i}) \text{ .......... (2)}$$

Where k is the number of horizons, SOCi is soil organic carbon concentration (Mg $m^{-2}$), ρi is the bulk density (Mg $m^{-3}$), Pi is the proportion of organic carbon (gC $g^{-1}$) in layer i, Di is the thickness of this layer (m), and Si is the volume fraction of fragments >2 mm.

Batjes [33] determined numerous factors that complicate global calculations of the pool of C in the soil. Among these factors include:

- There is still limited knowledge of the extent of different kinds of soils;
- There is limited availability of reliable, complete and uniform data for these soils;
- There is considerable spatial variation in SOC and N concentration, stoniness and bulk density of soils that have been classified similarly;
- And also there is confounding effects of climate, relief, parent material, vegetation and land use. Therefore, these factors can also complicate the calculations of SOC and N pool in various areas including the study area (i.e. Handeni District).

# RESULTS

Table 2 provides results of SOC and N accumulation in cropland areas with continuous sisal plantations. The results replicate the actual situation in various cropland areas. Alongside, Table 3 shows the results of other important nutrients such as zinc and magnesium that form important entity of soil nutrients.

The analysis as shown in Table 2 indicates that SOC was significantly higher in lowland (1.3 and 0.45 MgC $ha^{-1}$ at soil 0–20 cm and 20–40 cm depth) than in upland (0.60 and 0.34 MgC $ha^{-1}$ at 0–20 cm and 20–40 cm), respectively and they declined with increasing depths ($p<0.05$). Similarly, the findings reveal that the amount of N as indicated in Table 2 was higher in lowland (2.12 and 1.40 MgC $ha^{-1}$ at soil 0–20 cm and 20–40 cm depth) than in upland (1.80 and 1.16 MgC $ha^{-1}$ at 0–20 cm and 20–40 cm), respectively and they declined with increasing depths ($p<0.05$). Comparatively, these results exhibit that in both lowland and upland areas, the amount of SOC and N were higher on the top layer (0–20 cm) than that from beneath (20-40 cm), and diminished with increasing soil depth (Table 2).

Despite the fact that both areas were cultivated, it indicates that possibly lowland areas have sufficient SOC and N than in upland areas due to long term accumulations and ecological dynamics that favour the area. Moreover, as what happens in lowland; in the top-soils, the concentration of soil nutrients was higher than in the layers beneath. However, the difference of SOC accumulation between 0-20 and 20-40 cm was not significant ($p>0.05$). However, this difference is enough to recommend some adaptations and mitigation measures for various ecological restorations.

Consistently, Phosphorus (P) was significantly higher ($p<0.05$) in lowland than in upland and decreased from 2.49 and 2.12 Mg (0–20 cm) to 2.20 and 1.72 Mg (20–40 cm), respectively (Table 2). In addition, other important soil nutrients such as calcium ($Ca^{2+}$), potassium ($K^+$) and magnesium ($Mg^{2+}$) behaved the same way as seen in (Table 2 and 3).

The pH value of the soil increased significantly ($p<0.05$) from upland to lowland areas (Table 3). The soil pH was neutral as it ranged from 5.96 to 7.29 under both situations. Nonetheless, attention was least given to the trace elements as the study intensely focused on SOC.

**Table 2:** Analyses result of the major soil nutrients from the study area

| Field ref. | Depth (cm) | No. Samp | TN-Kjeld (%) | OC-BlkW (%) | Ext.P (mg/kg) PBry[1] | CEC ($cmolKg^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | CEC | $Ca^{2+}$ | $K^{+}$ |
| Lowland | 0–20 | 32 | 2.12 | 1.3 | 2.49 | 36 | 15.82 | 3.89 |
| Lowland | 20–40 | 32 | 1.4 | 0.45 | 2.12 | 31 | 11.81 | 2.84 |
| Upland | 0–20 | 32 | 1.8 | 0.6 | 2.2 | 37 | 7.58 | 1.68 |
| Upland | 20–40 | 32 | 1.16 | 0.34 | 1.72 | 28 | 5.73 | 0.97 |

**Note:** Lab soil analyses at Sokoine University of Agriculture (SUA), 2022

**Table 3:** Analyses result of the minor soil nutrients from the study area

| Field ref. | Depth (cm) | No. Samp | Soil pH (%) | $CaCl_2$ (%) | EC 200 µS/cm | Zn mg/kg | Mg mg/kg |
|---|---|---|---|---|---|---|---|
| Lowland | 0–20 | 32 | 5.96 | 6.16 | 34 | 0.89 | 6.23 |
| Lowland | 20–40 | 32 | 6.27 | 6.38 | 32 | 0.82 | 4.98 |
| Upland | 0–20 | 32 | 6.76 | 5.21 | 28 | 0.37 | 2.69 |
| Upland | 20–40 | 32 | 7.29 | 4.25 | 24 | 0.31 | 1.75 |

**Note:** Lab soil analyses at Sokoine University of Agriculture (SUA), 2022

In terms of soil physical properties, the content of moisture was higher in the lowland than in the upland. This difference reveals that the function of soil biological process is more significant in the lowland that in the upland [4,33]. Similarly, this situation indicates that the two locations have different capacities in biological functioning [8,34].

Together with, we determined soil Bulk Density (BD). The BD was normally expressed as the mass of an oven dry sample of intact soil per unit volume. In various studies, it is revealed that BD is among the most important soil physical property which is essential for assessing of SOC stocks [25]. Principally, BD determines the cumulative SOC in large area, therefore, it was important also to calculate SOC in large area (hectare) using the BD.

Since SOC was 1.30 and 0.45 in lowlands, and 0.60 and 0.34 in uplands, respectively, then, SOC accumulation was calculated by the following formula: SOC = Depth (cm) × Bulk density ($gcm^{-3}$) × Organic carbon (%).

Hence, the calculated SOC and N per hectare are determined as follows hereunder;

- SOC

Lowlands = 20 cm × 0.9 $gcm^{-3}$ × 1.30 MgC $ha^{-1}$ = 23.4 Mg $ha^{-1}$

Uplands = 20 cm × 1.1 $gcm^{-3}$ × 0.60 MgC $ha^{-1}$ = 13.2 Mg $ha^{-1}$

- N

Lowlands = 20 cm × 0.9 $gcm^{-3}$ × 2.12 MgC $ha^{-1}$ = 38.16 Mg $ha^{-1}$

Uplands = 20 cm × 1.1 $gcm^{-3}$ × 1.80 MgC $ha^{-1}$ = 39.60 Mg $ha^{-1}$

Thus, the amounts of SOC and N above have various economic and ecological implications. They act as a base for various agricultural and environmental planning.

## DISCUSSION

The present study establishes an assessment of SOC and N in cropland areas under sisal plantation as indicated in Tables 2 and 3. This is among the fewest studies which have estimated SOC and N stock in the cropland areas of Tanzania. Some of the prominent similar studies include that of Rossi [27] in the soil scapes of south-eastern Tanzania, and Hartemink [17] in the northern part of Tanzania. Although the results from these studies varied, most of them ranged from 2.1 and 0.25 MgC $ha^{-1}$ in 0-50 cm depth. Similarly, a study by Mäkipää et al. [6] estimated SOC and N in the general land and revealed that SOC varied over depth and locations. It was revealed that the SOC stock varied from 1.7 and 0.42 MgC $ha^{-1}$ over depths (0-50 cm) while N varied from 2.8 to 1.46 Mg over the same depth. This indicates that the SOC at topsoil was considerably higher than the present study and vice versa in the subsoil.

In addition, the study by Kempen et al. [35] mapped SOC and N on topsoil in Tanzania and revealed that among the areas with high SOC and N concentration in the country is along the eastern arc mountains, Lake Tanganyika and north-western Tanzania. Along the mountain, SOC varied from 1.9 and 0.38 MgC $ha^{-1}$ over depths (0-60 cm). Comparatively, these areas have more SOC deposits than in cropland areas. Interestingly, the amount of SOC and N seem to be high in fertile soils. This signifies that in most developed countries such as China and other parts of Asia where intensive agriculture is more pronounced, the amount of SOC and N in the soils is expected to be higher.

Coming to the findings of the present study, the results on SOC and N accumulation in the sisal plantations indicate that there is more SOC and N on the top soils (0–20 cm) than sub-soil (20–40 cm) (Tables 2 and 3). In terms of locations; SOC and N were higher in the lowland than in upland environments. The study by Mkonda and He [36] revealed similar patterns of SOC stocks in different depths under various soil treatments. This study exhibits that the SOC stock on the top soil (0-20 cm) and sub-soils was 1.15 and 0.80 MgC $ha^{-1}$ respectively, while that of the present study was 1.3 and 0.45 MgC $ha^{-1}$ in similar patterns. This indicates that there has been a variation in the amount of SOC and N based on soil type and management [24].

Despite the fact that the entire study area was under intensive sisal cultivation, it was revealed that the lowland had plenty nutrients deposits compared to upland areas. This variation is mainly attributed by topographic position (specifically ecological gradient). Factors like the differences in microclimate, topography, parent material, soil texture, soil drainage, soil nutrient status, salinity, and vegetation type can also intensify this variation [33,37].

The existence of more nutrients in the lowland has been more imperative in increasing yields and biological processes. This was experienced in areas where maize and legumes were planted along the rows. This benefit has also been adequately revealed in some previous studies for example in Ikerra et al. [38]. This study exhibits that the increase in SOC and N optimizes maize yields. Besides, a study by Kim et al. [39] revealed that SOC and N concentrations and pools are not significantly different between burned and unburned forest. This means, SOC and N stock is not significantly affected by forest fire especially under shifting cultivation.

The results of this study are evident from other studies conducted in different agro-ecological zones. The study by Bationo et al. [12], Batjes [33], Mäkipää et al. [6] and Mkonda and He [37] are some of them. However, there have been variations in the SOC and N storage over different soil treatments. Specifically, there has been significant difference in the storage of these soil nutrients between the areas with fertilization and those without it [36]. Beside, as established in Plaza-Bonilla et al. [28], there has been insignificant difference of SOC and N stock within the same soil conditions.

Empirically, the findings of the present study are fairly important to the replenishment of various biological processes including the functions in intensifying the capacity of nutrients uptake by various plants as stipulated in Hartemink [17] and Mkonda and He [37]. Biologically, the findings indicate that the lowland have multiple benefits compared to uplands. Alongside, in most incidences, quantifying SOC has been a mandatory measuring unit for assessing clean development mechanism [14,18].

The results further indicate that there had been a serious decline of SOC and N in the upland areas as seen in Table 2. Among other reasons, it has been revealed that relief and erosion agents have been more pronounced in the upland areas compared to the counterpart. This precisely indicates the essence of having the same ecosystems (farmland) with diverse amount of SOC and N deposits. The implications of this study include; we expect more active biological processes in the lowlands than in the uplands due to differential SOC and N deposits [10,12].

Moreover, in lowlands the ability of organic matter to retain cations for plant utilization while buffering them from leaching was higher than in uplands. The cation exchange capacity of organic matter as seen in Table 3 is mainly due to negative charges created as hydrogen ion removed from weak acids during neutralization [25,33].

Besides, organic matter also reduces or buffers the change of pH in the soil when acids or bases are added in the soils. If this situation happens; there can be improved vegetation in the area when other factors are kept constant [26,35,40]. Correspondingly, the findings reveal that there has been an increased difference in water content of soil between the lowlands and uplands. In this aspect, lowland soils were observed to have high retaining water capacity than uplands because of high organic matter contents which buffers moisture that would get lost through leaching [10,18,34].

Since most soil nutrients including SOC and N are resilient from losing moisture, the farmland with vegetation cover (especially weeds) acts as a sink for the first, second, and third largest greenhouse gases namely carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$), respectively. By sinking these greenhouse gases, we are mitigating climate change impacts as also stipulated in Intergovernmental Panel on Climate Change (IPCC) [41] and Haoa et al. [42]. To support this, several studies have specified that the amount of sequestered C is equivalent to that found in biomass ($p < 0.05$). Therefore, soil restoration always leads to C sink and vice versa [42,43].

To understand the duration of stored SOC and N in the soil is also very important. However, there have been differences in terms of how long will the stored SOC and N will remain in the soil. Most studies exhibit that SOC and N can stay for decades if not subjected to weathering. Weathering is among the factors that determines the time of SOC and N storage in the soil. A study by Groenigen et al. [14] reveals that the moderately weathered soils in seasonal climates with poorly-crystalline and reactive clay minerals stabilize organic C longer (centuries to millennia) as compared to highly weathered soils in humid regions with less reactive minerals.

In terms of climate, appropriate rainfall plays a substantial role in the process of accumulating C in the soil as it facilitates various biological processes. Contrary, extremely low rainfall leads to excessive drought that limits the production of plant biomass and formation of organic matter. Predominantly, the change in moisture content affects the decomposition of soil biomass as stipulated in IPCC [44] and Glaser et al. [4]. Various studies have realized that there is an exponential correlation between SOC and N accumulation and the precipitation of the area as established by Mäkipää et al. [6], Bationo et al. [12] and Batjes [33].

In addition, the increase in temperature and decrease in rainfall are likely to reduce the net primary productivity and net ecosystem productivity. However, it may not be easy to quantify the magnitude of the impacts. In this aspect, it can be concluded by affirming that there is a significant correlation between climate and SOC and N accumulation as also established by the United Nations Framework Convention on Climate Change [43].

Therefore, since SOC and N happened to be higher in the lowland under intensive sisal plantation, it can be recommended that the current land use be changed to other cropping systems in order to maximize the benefits accrued from the soils. The land use can be changed from the current sisal plantation to the production of cereal or leguminous crops in order to yield more food crops. Among others, this will improve food security in the area and the country at large as stipulated in Mkonda and He [45]. This land use can also optimize other biological and biochemical processes of the soils [11,18,33].

## CONCLUSION

The present study has shown the spatial variations of SOC and N content in cropland ecosystems soils of Tanzania. It has revealed that the lowland and top soil had high amount of SOC and N compared to lowland and subsoil. Specifically, it was also important to bring into attention on the understanding that the amount of SOC in lowlands was almost two times of that of the uplands. The study has met its objectives as it has revealed the differential accumulation of SOC and N in the cropland ecosystems although the estimation of how long the stored SOC and N will remain in the soils calls for further researches. The implications of this study can be appropriate across different soil types, climatic regions, vegetation types, and ecosystems. Due to socio-economic and ecological significance of SOC and N, it is imperative for environmental practitioners and policy advocacy groups to have this insight about environments for their planning and implementations of various environmental projects. Therefore, this study is more imperative to be into use particularly when the practitioners and environmental groups involved in the implementation of various projects activities related to conservation and environmental services across different agro-ecological zones of Tanzania and beyond the country.

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## CONFLICT OF INTEREST

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## AUTHOR CONTRIBUTIONS

The Author MYM designed the study, collected data, and prepared and wrote the whole manuscript.

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