

Effects of land use on Soil Organic Carbon fractions in soils of Njala Landscape in Sierra Leone

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Abstract— Soil organic carbon fractions reflect the difference in soil organic carbon from one land use to another, and it can be regarded as an indication of the degree of soil organic carbon deterioration or improvement. Although knowledge of importance soil quality indicators is vital for replenishing and maintaining soil fertility, little information is available on the effect of different land use management on soil organic matter fractions in Sierra Leone. In the present study, the effects of different land use on the distribution of soil organic matter fractions in soils of the Njala series was assessed. The study revealed both positive and negative effect of land uses on Organic carbon fractions at the Maturie site showed an increase upon conversion of grassland to tree cropping except for carbon in the silt+clay fraction. The total organic carbon, light fraction carbon and particulate organic carbon fractions were significantly greater in the forest soil than in soils under grassland. The decline in the silt+clay fraction organic carbon was an indication that residue decomposition and organic matter addition are low in this area. At the Old Agronomy Site, where *Acacia* and *Gliricidia* fallows were converted to agriculture (groundnut), soil organic carbon (SOC) contents showed a decrease under annual cropping land use types. The conversion of *Acacia* and *Gliricidia* land use to groundnut cultivation resulted in loss of total organic carbon and all carbon fractions. The largest decline was in the light fraction carbon (16.46%), followed by the particulate organic carbon (15.82%), total organic carbon (14.63%) and the silt+clay fraction (5.83%). The least decline occurring in the silt+clay fraction indicates that organic

matter is better protected in silt+clay fraction. Similar changes in soil organic carbon fractions, as observed for the Old Agronomy site, were observed at the NATC site. The results showed that there are greater losses of particulate organic carbon (17.24%), light fractions (18%) and total organic carbon (16.21) than from the silt+clay fraction (7.34) when the land use is changed from secondary forest to arable cropping.

Keywords— Soil organic carbon, Sierra Leone, degradation, vegetation, land use, soil quality, soil productivity, Njala.

I. INTRODUCTION

Soil organic carbon (SOC) and soil organic matter (SOM) play a fundamental role in sustaining soil and environmental quality. SOM has been increasingly recognized as an indicator of soil quality that is a component of biosphere sustainability and stability [1]. Soil organic carbon in agricultural soils is of increasing interest. However, there is little experimental evidence on SOC and both total and extractable SOM in differently used agricultural lands, especially those describing changes resulting from land use conversion. Ideal settings to sequester organic carbon in soils are found in the environments that promote minimum soil disturbance [2]. Land use has an influence on the biomass stock of ecosystems [3]. A change in land use from forest or grassland to cropland will, therefore, lead to a loss of soil organic carbon (SOC) [4]. [5] reported that conversion of cropland to alfalfa resulted in a greater SOC as well as N accumulation in the 0–5 cm layer. Soil C/N ratios tended to

increase in grassland and alfalfa soils compared with cropped soils. Land use is an integrator of several environmental attributes which influence soil organic matter fraction [6].

The rate of soil organic matter degradation depends on land use systems, soil types, topography, and climatic conditions. Among these factors, inappropriate land use aggravates the degradation of soil physical, chemical and biological properties [7]. According to [8], land use affects basic processes such as erosion, soil structure and aggregate stability, nutrient cycling, leaching, carbon sequestration, and other similar physical and biochemical processes. The importance of soil organic matter fractions on soil properties is well known. It influences plant productivity [9], soil structure and the distribution of soil micro-organisms [10]. In many ecosystems, equilibrium levels of soil organic matter are determined by plant biomass production, stabilization and mineralization of organic compounds. When this equilibrium is changed by introduction of new agricultural practices, soil organic matter contents are modified. However, ranges of modifications depend upon climatic conditions, land uses, soil types, and soil texture. Experimental evidence suggests that land use conversion has both positive and negative effects on soil total and extractable carbon and SOM. In Puerto Rico, [11] observed that decreases of soil organic carbon under cultivation were more important under moist climatic conditions than under dry conditions. One year after clearing a tropical rainforest, organic carbon content in the 0–15 cm layer of an Ultisol was 25% lower than before. In Albeluvisols, grassland soil was found to contain by 0.2-0.6 g kg⁻¹ more C compared to fallow land (1-1.5 years old).

Soil organic matter fractions can respond rapidly to changes in land use. These fractions have therefore been suggested as early indicators of the effects of land use on soil organic matter quality [12], as well as important indicators of soil quality. Recently, there has been increased interest in the importance of microbiological properties as indicators of change in soil quality [13]. [14] reported that hot water-extractable C could be used as an integrated measure of soil quality. However, the majority of studies on the labile organic matter fractions in other countries have used only topsoil samples based on the assumption that land use effects occur mainly in the uppermost few centimeters. Much less is known, however, on the impact of different land use systems on labile organic matter fractions, as well as distribution of labile organic matter through the soil profile depth.

In Sierra Leone, majority of the population is still dependent on forest and agriculture. Maintenance and improvement of soil organic matter is therefore a prime concern. Information regarding the status organic matter (SOM) in soils under different land uses in Sierra Leone is scarce. However soil degradation due to inappropriate land use system is threatening the livelihood of thousands of people [15]. Similarly, large areas of land are abandoned within less than three decades of continuous cultivation. Although knowledge of importance soil quality indicators is vital for replenishing and maintaining soil fertility, little information is available on the effect of different land-use management on soil organic matter fractions in Sierra Leone. Keeping this view in mind, this study was undertaken to assess the effects of different land use on the distribution of soil organic matter fractions in soils of the Njala series.

II. MATERIALS AND METHODS

2.1. Description of study area

Njala area (Fig. 1) is situated on 8° 7' North Latitude and 12° 5' West Longitude in Kori Chiefdom, Moyamba District in the Southern Province of Sierra Leone. It is bounded on the east by the main Freetown-Bo highway, except for a small area east of this road near Bonganema and also on northwest of Taiama. The Taia River, one of the famous rivers in Sierra Leone, forms the western boundary. Njala is a famous and popular community as the name not only precedes but also hosts the famous and popular Njala University, which are Sierra Leone's first most renowned university for agricultural studies. The climate of Njala is warm to hot, with marked rainy and dry seasons. The annual rainfall is high averaging 2,750 mm. However, about 90% of this rainfall occurs during the rainy season from May to November. Hence, leaving the other 5 months with no more than 250 mm of rainfall.

2.2. Description of soils of Njala series

According to [16], Njala series comprised of nearly level and sloping uplands on a dissected peneplain. The nearly level areas having slopes of 0-3% occur at three different elevations: 76.2–91.4 m, 61.0 m, and 45.7 m. The latter coincides with the colluvial footslopes and the highest, river terraces. The sloping areas, usually 3–15% gradient occur between the nearly level summits and downward to the terraces of the Taia River and its tributaries. The parent material is gravelly colluviums overlying gravelly residual material over weathered bedrock, which is always found at a depth of more than 1.2 m. The colluvial plinthite gravels are rounded, hard and dense, with dusky red to reddish black colours. The gravel content of the colluvial surface

layer is usually 40–47% by volume; the thickness of the layer varies from 0.8–1.5 m. The residual plinthite gravels are more irregular, relatively more porous and soft, and are formed in-situ. Colours are brighter red (10R 4/6). The gravel content varies from 35–45%, gradually declining with depth and gravel is replaced at about 2.4 m or more by

red plinthite mottles in a light grey to white matrix. The total thickness of both colluvial and residual gravelly layers may be up to 3.1 m or more. Quartz veins may be present in the residual materials while quartz gravels may be present in the whole profile, being relatively rounded in the colluvial layers and relatively angular in the residual layers.

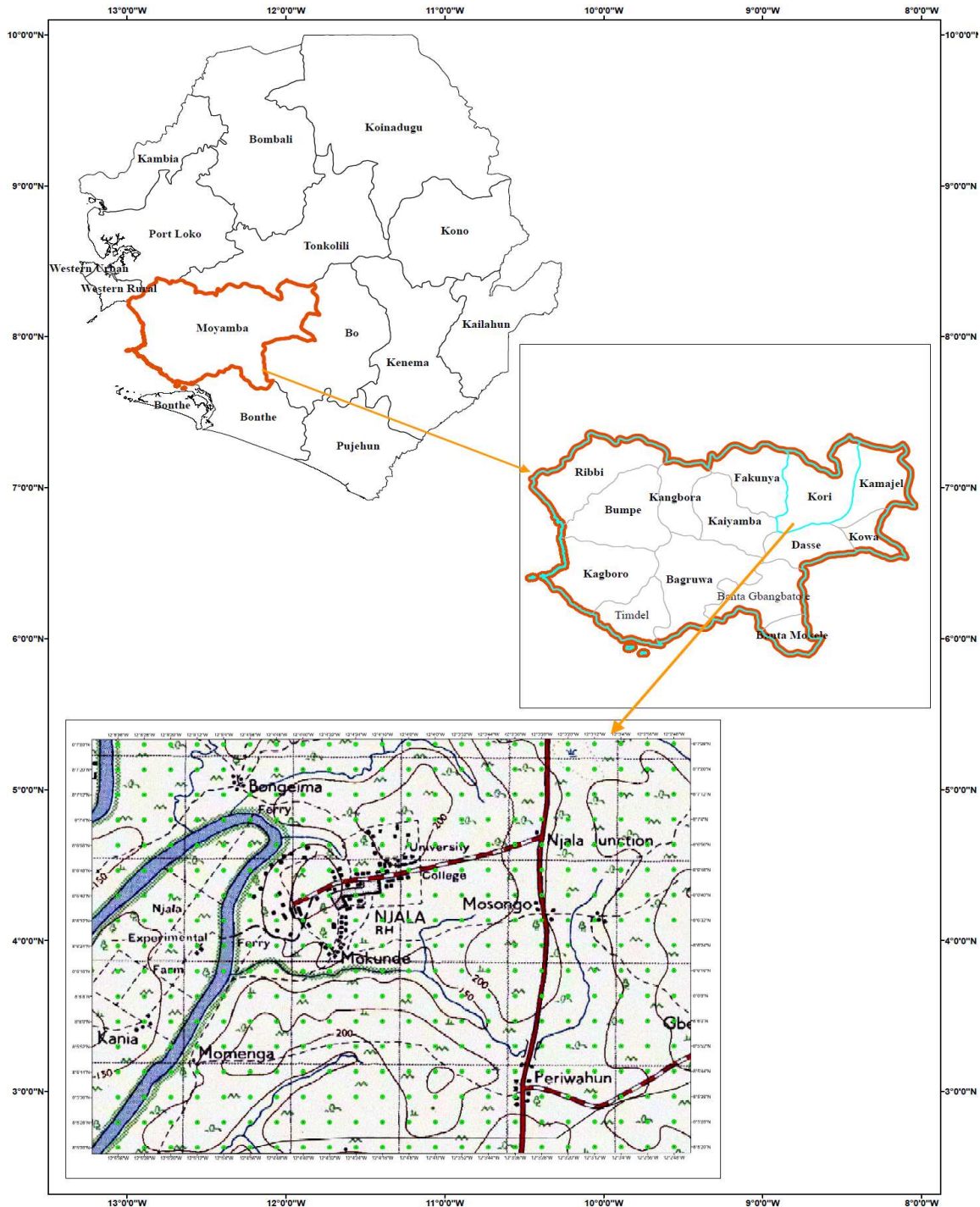


Fig. 1: Map of study area showing Njala landscape

The gravel-free surface layer is thin or absent, often depending on topography. Textures are usually gravelly clay loam in the surface soils and gravelly clay loam in the subsoil. Topsoil colours are very dark grayish brown to dark yellowish brown (10YR-7.5YR 5/8-7/6). Red mottles may or may not be present. The soils are well to moderately well drain and are never waterlogged. The A horizon is usually less than 30 cm thick (Ochric epipedon). Njala soils have a very low nutrient status for plants. Except for the A horizon, the cation exchange capacity is less than 10 cmol(p+)/kg. Exchangeable content of Ca, Mg, K, and Na are low. In comparison with other soils like the Momenga soils, the exchangeable Al content of Njala soils is lower, pH (in KCl) is higher, and the available water holding capacity is much lower. The base saturation is very low. The organic carbon content of the A horizon is moderate (about 3%), but it declines sharply with depth (to about 0.5%). The erosion hazard is slight on nearly level areas and moderate on sloping areas. Runoff is low to moderate; permeability is rapid. Njala soils are very low in moisture content during approximately 5 months of the severe dry season.

2.3. Soil sample collection

Soil samples were collected from 0–20 cm depth from three different land use locations following the guidelines outlined in the Soil Survey Manual as follows:

Site I= Planted forest plots at the back of the Matturie hostels

Site II = The old agronomy buildings by SLARi

Site III = The School of Agriculture (NATC) forest

Site I

- i) Two composite samples were taken from four different plots, each having a uniform type of forest tree planted with *Terminalis ivorensis*, *Tectona grandis*, *Commelina arborea*, and *Eucalyptus caradulensis*. A final sub-sample was taken from a land cultivated with the *Gmelina arborea*.
- ii) Five sub-samples were also taken from fallowed grassland

Site II

Three composite samples were taken from this site as follows:

- i. Five sub-samples from a fallow grassland
- ii. Five sub-samples from a *Gliricidia sepium* planted plot, and
- iii. Five sub-samples from an *Acacia* planted plot

Site III

Two composite samples were taken from this area as follows:

- i. Five sub-samples from a undisturbed natural forest that has been abandoned for over forty years,
- ii. Five sub-samples from a grassland area. In total, seven composite samples were obtained by sampling to a depth of 20cm with an auger.

2.4. Soil Analysis

2.4.1. Soil sample preparation

The collected soil samples were taken to the laboratory, air-dried for two weeks, crushed with mortar and pestle, sieved through a 2mm sieve and stored for analysis. Soil analysis was carried out at the Soil Analysis Laboratory of the Njala Agricultural research Center (NARC-SLARi) at Mokonde, Njala Campus following standard analytical procedures as outlined below:

2.4.2. Determination of soil organic carbon

Organic carbon content of the soils from the different plots was determined by following the Walkley-Black procedure [18]. Soil samples were grounded to pass through a 0.2mm sieve and 0.5g of each grounded sample was weighed and transferred into a 500mL wide mouth Erlenmeyer flask. 10mL of 1N $K_2Cr_2O_7$ was added to each weighed sample and stirred gently to disperse the soil particles in the solution. This was immediately followed by the addition of 20mL of concentrated sulphuric acid (H_2SO_4), and immediately covered to prevent heat loss followed by vigorous swirling for one minute. After 30 minutes standing, 200mL of water was added to the solution followed by 10mL of orthophosphoric acid and gently swirled and allowed to cool. After cooling, the solution was titrated using 0.5M $FeSO_4$, by using a phenolphthalein indicator.

From the titration results, the percent organic carbon was calculated, using the following formula:

$$\text{Percent Organic Carbon} = [M_{Fe^{2+}} (V_{Fe^{2+}} \cdot V_s) \times 0.3] / M_s$$

2.4.3. Isolation of the light fraction

The light fraction was isolated according to the method described by [19]. A 20g of air-dried soil was placed in 100ml of water in a 150ml beaker. The mixture was stirred with a rubber policeman and allowed to settle while allowing the light fraction to float on the surface. The supernatant containing the floating matter was poured onto a $<53\mu m$ sieve. This procedure was repeated for several times until the floating matter (light fraction) was visible on the upper portion of the solution. The light fraction material

on the $53\mu\text{m}$ sieve was then backwashed with distilled water on an aluminium tray and dried at 70°C in an oven. The weight of the oven-dried sample was recorded.

2.4.4. Determination of organic carbon in the light fraction

The oven dried light fraction was ground and 0.05g of the ground material was placed in a 500ml Erlenmeyer flask. 10ml of potassium dichromate ($\text{K}_2\text{C}_2\text{O}_7$) was added to the sample in the flask and swirled gently to disperse the soil in the solution. 20ml of concentrated sulphuric acid was rapidly added to the solution and covered directing the steam into the suspension. The flask was swirled gently for about 1 minute and allowed to stand for about 30 minute. 200ml of water was then added to the flask followed by 10ml of concentrated orthophosphoric acid. The flask and its contents was swirled gently and allowed to cool down. The solution was then titrated with 0.5M FeSO_4 solution.

2.4.5. Determination of particulate organic carbon (POC)

Dispersing agent was 3% Sodium hexametaphosphate solution made by dissolving 30g (NaPO_3)₆ in water in a 1L volumetric flask and made to volume. Sodium Chloride saturated solution was made by dissolving 175g NaCl in 1L warm water and cooled. A 200g of air-dried soil was weighed and transferred into a 250ml shaking bottle. 20ml of dispersion agent and 150ml of water was added and shaken overnight, lengthwise, horizontal position in a reciprocating shaker at 150 r.p.m.

The slurry with water was transferred into a $50\mu\text{m}$ sieve and placed in a funnel on top of a 1000ml measuring cylinder. It

was then sieved by pressing and stirring smoothly with a rubber plunger until the percolating water was almost clear. Care was taken so that the volume does not exceed the 1000ml mark. This was stirred thoroughly and the suspension was checked properly.

The fraction $>50\mu\text{m}$ was transferred to a tray, dried overnight at 105°C and weighed. The small quantity of organic matter floating in the tray was decanted. This is however not allowed in case of peaty samples.

III. RESULTS AND DISCUSSION

3.1 Effect of land use on soil organic carbon fractions at Site I (Maturie Hostels)

Organic carbon fractions at the Maturie site shows an increase upon conversion of grassland to tree cropping except for carbon in the silt+clay fraction (Table 1). Generally, cultivation results in a decline in soil organic carbon and the active fractions of soil organic carbon are particularly sensitive to land use changes [20,21]. The results show that the total organic carbon, light fraction carbon and particulate organic carbon fractions are significantly greater in the forest soil than in soils under grassland. This result is expected because of the intense litter recycling taking place in forest soils [22] Therefore the increase in soil organic carbon fractions under forest land use may be attributed to the incorporation of large quantities of grass biomass during tillage. The decline in the organic carbon in the silt+clay fraction is an indication that residue decomposition and organic matter addition might not have reached the stage where it becomes incorporated into the smaller fractions to account for any effect.

Table 1: Changes in soil organic carbon fractions following conversion of grassland to forest at Site I (Maturie Hostels)

Site I	Vegetation	Periods (Years)	TOC* (gCkg ⁻¹ soil)	LFC* (gCkg ⁻¹ soil)	POC* (gCkg ⁻¹ soil)	S+C* (gCkg ⁻¹ soil)
Uncropped	Grassland	15	32.0	0.8	6.7	5.5
Cropped	Planted forest trees	2	53.0	1.4	9.8	4.8
% change	-	-	+65.6	+64.6	+45.5	-13.2

* TOC = Total Organic Carbon; LFC = Light Fraction Carbon; POC = Particulate Organic Carbon; S+C = Silt + Clay Fraction Organic Carbon.

4.2 Effect of land use on soil organic carbon fractions at Site II (Old Agronomy Site)

Two different land use changes have occurred on this site: Acacia fallow has been converted to cropland (groundnut cultivation) and Gliricidia fallow to cropland (groundnut) (Table 2a & 2b). As expected, soil organic carbon (SOC)

contents are lowest in the annual cropping land use types. This is most probably due to the widely practiced burning of crop residues [23], which causes nutrient levels to be generally very low, pointing to highly leached and inherently low fertility soils, a condition that is frequently found in most upland soils of Sierra Leone. In the case of arable land use, the high utilization of organic matter by the

groundnut and a high mineralization rate due to exposure to high temperature might be a possible reason for the low soil organic carbon recorded. According to [22], organic matter

input is low in arable land use, thus giving rise to the low organic carbon content observed in soils under this land use.

Table 2a: Changes in soil organic carbon fractions following conversion of Acacia woodlot to agricultural crop production at Site II (Old Agronomy Site)

Site II	Vegetation	Periods (Yrs)	TOC (gCkg ⁻¹ soil)	LFC (gCkg ⁻¹ soil)	POC (gCkg ⁻¹ soil)	S+C (gCkg ⁻¹ soil)
Uncropped	Acacia	15	41.0	1.6	5.5	2.4
Cropped	Groundnut	2	36.0	1.3	4.6	2.3
% change	-	-	-14.6	-16.5	-15.8	-5.8

* TOC = Total Organic Carbon; LFC = Light Fraction Carbon; POC = Particulate Organic Carbon; S+C = Silt + Clay Fraction Organic Carbon.

Conversion of Acacia land use to groundnut cultivation resulted in loss of total organic carbon and all carbon fractions (Table 2a). The largest decline was in the light fraction carbon (16.5%), followed by the particulate organic carbon (15.8%), total organic carbon (14.6%) and the silt+clay fraction (5.8%). The light fraction is considered to be the labile form of soil organic matter [24, 25] and is therefore more susceptible to loss upon cultivation. The least decline occurring in the silt+clay fraction indicates that organic matter is better protected in silt+clay fraction.

Similar patterns of change were also observed when Gliricidia fallow was converted to groundnut cropping (Table 2b). However, land use change in this case resulted in greater depletion of soil organic carbon fractions than in conversion of acacia land use to groundnut cropping. This might be due to the differences in the quality of organic inputs from the two dominant vegetations on this site. Gliricidia has a lower C/N ratio than acacia and is therefore

more easily decomposed than acacia. Plant residues like Gliricidia, which has a narrow C/N ratio decompose quickly with rapid rate of humification but the amount of humus produced is limited by the amount of carbon present in the original residue. Thus carbon fractions resulting from the decomposition of acacia are more resistant to degradation and therefore persist for longer times than those resulting from Gliricidia decomposition. The lower levels of soil organic carbon fractions in cultivated soils may have resulted from a combination of low carbon inputs because of less biomass C return on harvested land and greater C losses because of aggregate disruption, increased aeration by tillage, crop residue burning, accelerated water erosion and livestock grazing [26, 27]. In contrast, higher soil organic carbon contents of soils under Acacia and Gliricidia land uses are probably due to higher litter production and N fixation by the leguminous Acacia [28] and Gliricidia biomass.

Table 2b: Changes in soil organic carbon fractions following conversion of Gliricidia woodlot to agricultural crop production at Site II (Old Agronomy Site)

Site II	Vegetation	Periods (Years)	TOC (gCkg ⁻¹ soil)	LFC (gCkg ⁻¹ soil)	POC (gCkg ⁻¹ soil)	S+C (gCkg ⁻¹ soil)
Uncropped	Gliricidia	15	28.0	1.6	5.0	2.3
Cropped	Groundnut	2	24.0	1.2	4.1	2.1
% change	-	-	-14.3	-22.6	-17.8	-11.9

* TOC = Total Organic Carbon; LFC = Light Fraction Carbon; POC = Particulate Organic Carbon; S+C = Silt + Clay Fraction Organic Carbon.

3.3 Effect of land use on soil organic carbon fractions at Site III (NATC Site)

At the NATC site, there has been a change from secondary forest to agriculture (mainly cassava cultivation). Similar changes in soil organic carbon fractions, as observed for the

Old Agronomy site, have also taken place on the NATC site. There were greater losses of particulate organic carbon (17.2%), light fractions (18%) and total organic carbon (16.2%) than from the silt+clay fraction (7.3) when the land use is changed from secondary forest to arable cropping. This confirms other studies which reported that soil organic

carbon is higher in forest soils compared with cultivated fields [29]. Some researchers reported that the highest organic matter content is found in grasslands compared to agricultural fields [30, 31]. The depletion of organic matter

in the cultivated field can be associated with the intensive tillage and the removal of plant residue. The results indicate that cultivation decreases soil nutrient levels, as has been noted by many authors [32, 33, 34].

Table 3: Changes in organic carbon fractions following conversion of secondary forest to agricultural crop production at Site III (NATC Site)

Site III	Vegetation	Periods (Years)	TOC (gCkg ⁻¹ soil)	LFC (gCkg ⁻¹ soil)	POC (gCkg ⁻¹ soil)	S+C (gCkg ⁻¹ soil)
Uncropped	Secondary forest	15.0	37.0	0.5	4.9	2.5
Cropped	Cassava	2.0	31.0	0.4	4.1	2.3
% change	-	-	-16.2	-18.0	-17.2	-7.3

* TOC = Total Organic Carbon; LFC = Light Fraction Carbon; POC = Particulate Organic Carbon; S+C = Silt + Clay Fraction Organic Carbon

IV. CONCLUSION

As the percent change in soil organic carbon fractions reflects the difference in soil organic carbon from one land use to another, it can be regarded as an indication of the degree of soil organic carbon deterioration or improvement. The positive value shows improvement of the soil organic carbon, whereas negative value indicates deterioration of the soil organic carbon. Across the three sites, there has been greater reduction in soil organic carbon fractions when forest land use is converted to agricultural land use. Clearing and cultivation of forest lands resulted in deterioration of soil organic carbon compared to soils under forest, Acacia and Gliricidia land uses. Cultivated soils showed low soil organic carbon fractions. Total organic C, light fraction C, particulate organic C and silt+clay organic C fractions were all reduced. Improvement of total organic C, light fraction C, and particulate organic C under planted forest land use at Maturie site indicates that planting of well-adapted and fast-growing tree species can gradually improve soil quality and regenerate degraded lands. The study has revealed that soil organic carbon is best protected in the silt+clay fraction under grassland use, and the incorporation of residues during tillage could increase soil organic matter fractions in soils of the Njala series. The level of crop residue addition should be increased in order to increase the level of soil organic matter. A further research is needed to determine the Microbial Biomass Carbon, KMnO₄ soluble carbon, water soluble carbon and KMnO₄ soluble carbon. The results of such research can be compared with the current results to see if they show any correlation. There is need for faster organic matter restoration through the addition of organic residues in the Njala landscape.

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