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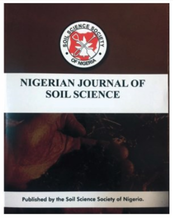

Impact of Land Use/cover on Carbon Sequestration in Afaka Forest Reserve, Northern Guinea Savanna of Nigerian

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ABSTRACT

This study aims to assess the impact of land use/cover on carbon sequestration in Afaka Forest Reserve. Six (6) land use/cover types were delineated and used in the study area. This includes Eucalyptus plantation (EP), Farmland (FL), Gmelina plantation (GP), Mixed plantation (MP), Natural plantation (NP) and Teak plantation (TP). A profile pit was dug in the middle of each of the delineated land use/cover. Soil samples were collected from master horizon of the profile pits and analyzed using standard procedures. The result showed that soils under EP were significantly ($P < 0.05$) higher in micro aggregate (15.9), silt and clay aggregates (4.45) and mean weight diameter (MWD) (0.62) while soils under FL recorded the least value for micro aggregate (7.14) and silt and clay aggregates (1.45). Soils under EP sequestered significantly ($P < 0.05$) higher carbon in all the pools (Labile carbon, Intra aggregate particulate, silt plus clay, non-hydrolyzable and total carbon) than the other land use/cover while FL recorded the least values. Surface soils sequestered significantly ($P < 0.05$) higher carbon (9.1 g kg^{-1}) than subsoils (2.2 g kg^{-1}). Labile carbon was higher than non-labile carbon in all the land use types. Total C significantly ($P < 0.01$) correlated with all carbon pools. Soils under EP, NP and MP were best suited for sustainable land management and climate change mitigation relative to the other land use/cover due to higher aggregation and carbon sequestration. Unsustainable management practices decreased MWD and all the carbon pools, thus increased climate change severity.

1.0 Introduction

Soil carbon sequestration (SCS) refers to the removal of carbon from the atmosphere through photosynthesis, dissolution and storage in the soil as organic matter (OM) or secondary carbonates (Lal, 2005). Soil organic carbon can be classified into two major pools based on their residence time i.e., labile and non-labile pool. Labile pool (active pool) is the most sensitive pool that is easily influenced by management and environmental changes. Labile pool decomposes and gets oxidized rapidly with changes in land use practice (Haynes, 2005). The non-labile pool (passive pool) is a more stable and recalcitrant pool of SOC forming organic-mineral complexes with clay mineral and gets decomposed slowly by microbial activity (Wiesenberg *et al.,* 2010; Gemma *et al.*, 2017).

Land use/cover types and the management of agroecosystems have the potential to either release a considerable amount of SOC stored in the soil, thus leading to global warming and climate change or promote carbon sequestration in soil, thus reducing atmospheric carbondioxide (CO_2) concentration (Lal, 2005). Thus land use/cover changes could make the soil a source or sink for greenhouse gasses. Soil organic carbon is sensitive to changes in land use/cover, and a change from forest ecosystem to agricultural ecosystems often lead to significant changes in SOC content and vice versa (Wilson *et al.*, 2008; Poeplau and Don, 2013). Deforestation and continuous cultivation significantly reduce soil aggregation, organic matter, and other nutrient reserves by fastening mineralization, reducing replenishment through litter fall and increasing soil erosion, that results to land degradation (Wilson *et al.*, 2008; Odunze, 2015). Soil organic matter associated with different soil size aggregates differ in structure and function and play different roles in soil organic carbon resident time (Christensen, 1992).

There is limited research on the impact of land use/cover on carbon sequestration across aggregate size fractions under soil profile in Northern Guinea savanna of Nigerian. Previous studies in Nigeria (Raji and Ogunwole, 2006; Anikwe, 2010; Lawal, 2013; Odunze *et al.,* 2019) mainly focus on the impact of land use/cover on carbon sequestration under surface soils. Carbon stored in micro-aggregates and silt + clay at subsoils are more stable and have more resident time as it is associated with clay (Gemma *et al.,* 2017). The need arises for this study for accurate estimation of carbon for sustainable land management. Therefore, the aims of this study was to assess the impact of land use/cover on carbon sequestration across aggregate size fractions in Afaka forest reserve, Northern Guinea savanna of Nigerian.

2.0 Materials and Methods

2.1 Study Area

The study area is located in Afaka Forest Reserve (10^{O}36'22"N - 10^{O}37'12"N and 7^{O}14'10"E - 7^{O}17'0"E) near Kaduna in Northern Guinea savanna of Nigeria (Figure 1). The reserve covers an area of 10,927 ha, characterized by Northern Guinea savanna vegetation type (Abaje *et al.,* 2015). The area lies within savanna region with distinct wet and dry season (Kowal and Knabe, 1972). The region is characterized by dry season from November through March and wet season from April to October with mean annual rainfall of 1032 mm (Abaje *et al.,* 2015). Temperature ranges from 22^{0}C during cold night to over 38^{0}C during hot days. The relative humidity ranges from 15 % during dry season to 60 % during rainy season (Kowal and Knabe, 1972). The geology of the area lies within high plains of Northern Nigeria characterized by inselbergs and pediment landscape overlying basement complex which are nearly level to gentle undulating plains (Abaje *et al.,* 2015).

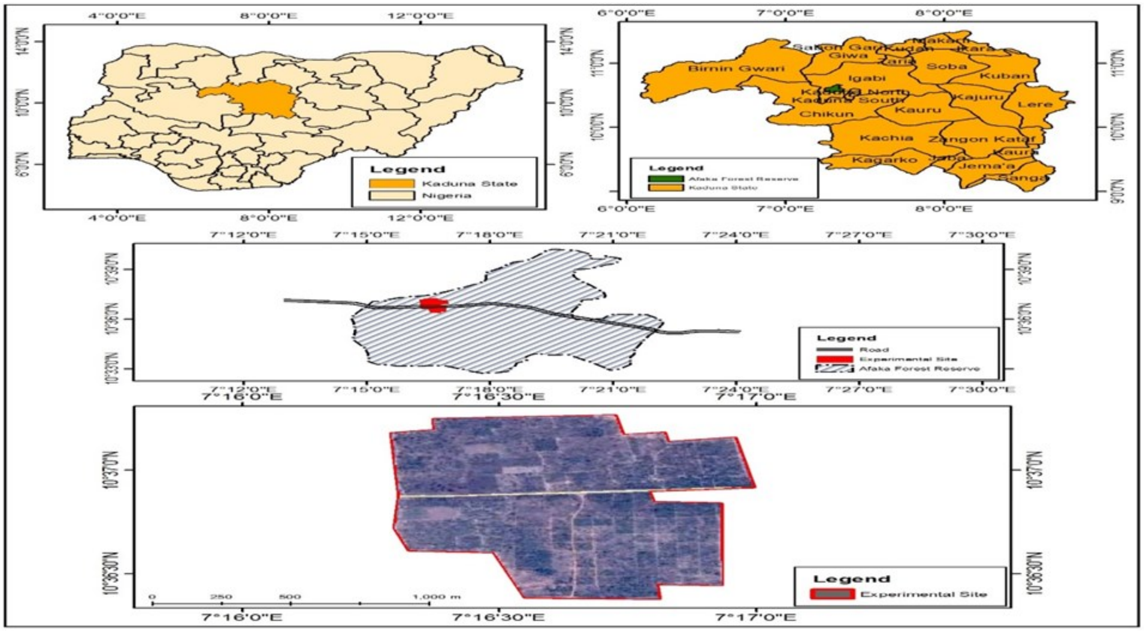

Figure 1: Nigeria, showing Kaduna, Afaka Forest Reserve

2.2 Field Design

Six (6) dominant land use/cover types were identified namely: *Eucalyptus camaldulensis,* (Eucalyptus) *Tectona grandis* (Teak), *Gmelina arborea* (Gmelina), Mixed plantations (Eucalyptus spp, Teak, Gmelina and natural tree species), Natural plantations (*Antiaris africana, Khaya senegalensis and Isoberlinia doka* etc.) represent the land cover and Farm land which were previously under plantations represent the land use. Eighteen (18) soil samples were collected from genetic horizons of six (6) profile pits dug on each land use/cover identified and stored in properly labeled polythene bags. The soil samples were air-dried and used for all laboratory analyses.

2.3 Laboratory Analyses

Aggregate stability was determined by dry sieving method as described by Van Bavel (1950). Two hundred grams (200 g) of air-dried soils (passed through 6.35 mm sieve) were placed in a nest of four sieves (2.00 mm, 0.25 mm, 0.053 mm and < 0.053 mm) attached to a sieve shaker. These sieve sizes were chosen to separate soil aggregates as large macro-aggregates (6.35 – 2.00 mm), small macro-aggregates (2.00 – 0.25 mm), micro aggregates (0.25 - 0.053 mm) and less than 0.053 mm fractions made up of silt + clay fractions. The sieves were shaken for 5 minutes and the aggregates retained in each sieve and those that passed through the last sieve were weighed. Soil samples obtained were used to determine aggregate size distribution and in the calculation of mean weight diameter (MWD) for structural quality. Mean weight diameter was calculated by summing the product of mean diameter aggregates and proportion of soil in each aggregate size class as given in the equation below.

Mean weight diameter (MWD) was determined thus:

$$\text{MWD} = \sum_{k=1}^{n} wi\ xi$$

where xi = mean diameter of sieve proceeding and
wi = proportional weight of sand free aggregates.

2.4 Soil organic carbon fractionation

Soil organic carbon fractions were determined in each of the aggregate fractions (2.00 - 0.25, 0.25 - 0.053 and < 0.053 mm) using Walkley-Black dichromate wet oxidation method as described by Nelson and Sommers (1982).

Table 1: Soil Carbon Fractions

Sieve size	Measure organic carbon	Conceptual soil organic carbon
2.00 - 0.25 mm	Fine particulate organic carbon	Unprotected
0.25 - 0.053 mm	Intra aggregate particulate organic carbon	Physically protected
< 0.053 mm	Silt and clay associated organic carbon	Chemically protected

The biochemically protected soil organic carbon was determined following the acid hydrolysis procedures described by Tan *et al.* (2004). Non hydrolysable carbon was determined by dichromate oxidation methods (Nelson and Sommers, 1982). The non hydrolysable organic carbon were referred to as biochemical protected organic carbon.

Statistical Analysis

Two-ways analysis of variance (ANOVA) was used to assess the variation in soil aggregate fractions and carbon pools under the land use/covers and soil depth using general linear model (GLM) procedure. Mean comparison were done using fisher's least significant difference test at $P < 0.05$ significant level, while soil aggregate fractions were correlated with the carbon pools all in statistical packages for social science (SPSS) software version 23 (SPSS, 2015).

3.0 Results and discussions

3.1 Aggregate Stability

The results of effects of land use/cover and soil depth on dry stable aggregate (DSA) were presented in Table 2. Large macro, small macro aggregates and MWD were not significantly different; suggesting the land use/covers did not differ significantly in developing macro aggregates in the soils. However, soils under EP were significantly ($P < 0.05$) higher in micro aggregates (15.9) and silt + clay aggregates (4.5) than other land uses. Also, micro aggregates (14.54) and silt + clay aggregates (3.75) were significantly ($P < 0.05$) improved at the surface layers than sub surface (Table 2). Aggregate stability is very useful in maintaining balance between the soil constituent (air and water) and the root development (Odunze, 2015). The higher mean weight diameter in soils under EP and NP implies balanced soil air and water that will favour plant root development for sustainable forest growth. The consistencies of soils under EP recording the highest macro and micro aggregate fractions, the highest value of silt and clay aggregates and MWD would be attributed to the higher organic carbon content of soils under EP. Mean weight diameters which were not significantly different with land use/cover was similar to the findings of Odunze *et al.,* (2017) who also reported non-significant difference in MWD with respect to the land uses in soils of Nigeria Savanna. In contrast, Lawal (2013) reported a significant difference in MWD with respect to land use in Afaka forest, which could be as a result of the methods of assessment employed, as this study adopted dry sieving while Lawal (2013) used wet sieving. Generally, soil aggregate stability is enhanced with increase in organic matter as a result of improvement in amount of organic derived binding agents from microbial activities on plant residues in soil (Paul *et al.,* 2003). Low micro aggregate fractions and proportions of silt + clay aggregates were observed under soils of FL. This was attributed to the relative low soil organic carbon which would have helped in binding soil particles together. Soils under TP were expected to have higher aggregation due to its deciduous characteristic; but perhaps, the wildfire by hunters burnt plant residues thus depleted soils organic carbon and also reduced the rate of aggregation. The low aggregation under TP could also be attributed to leathery leaves of teak plantation (Keay, 1989) that does not decompose easily. Hence organic matter derived binding agent will be low in production and will lead to low rate of soil aggregation relative to other plantations. Lawal, (2013) also reported low aggregate stability value under Teak plantation despite its deciduous nature which was expected to support high level of aggregation. The high proportion of smaller micro-aggregates at surface soils of all the land use/cover could be as a result of consistent accumulation of residues on soil surfaces, which serve as mulch and seemed to improve soil aggregation. Similarly, Lawal (2013) had reported higher micro aggregate within 25 cm depth of soils of Afaka forest.

Table 2: Effect of sampling depth and land use on dry stable soil aggregates

Means	Large macro aggregate (6.35 – 2.0 mm)	Small macro aggregate (2.0 - 0.25 mm)	Micro aggregate (0.25 - 0.053 mm)	Silt and clay aggregates (< 0.053 mm)	MWD (<2mm)
EP	26.39a	55.16a	15.88a	4.45a	0.62a
FL	48.88a	44.84a	7.14b	1.45b	0.52a
GP	45.79a	45.89a	8.35ab	1.88b	0.53a
MP	49.9a	38.06a	10.20ab	3.62ab	0.44a
NP	37.31a	48.99a	12.44ab	2.95ab	0.57a
TP	44.6a	46.25a	8.43ab	2.61ab	0.54a
P-value	0.3103	0.5983	0.2193	0.1145	0.658
LOS	NS	NS	NS	NS	NS
SE+	8.3814	7.074	2.7485	0.794	0.0210
Depth					
Surface (0 – 18cm)	35.92a	47.68a	14.535a	3.75a	0.56a
Subsoils (19 – 110cm)	51.007a	44.02a	5.372b	1.61b	0.58a
P-value	0.1659	0.7968	0.0126	0.0359	0.198
LOS	NS	NS	**	*	NS
SE+	5.9267	5.0021	1.9435	0.5614	0.067

Note: EP = Eucalyptus, FL = Farmland, GP = Gmelina, MP = Mixed Plantation, NP = Natural Plantation, TP = Teak Plantation, Means followed by similar letter are not significant at 5% level.

Accumulation of litter fall on top soils bind soil aggregate together which helps to reduce loss of soil organic matter (Beare *et al.*, 1994). The organic matter from decayed leaves and roots produces humic substances that was reported to influence soil physical, chemical and biological properties (Lawal, 2013).

3.2 Soil Carbon Pool

Table 3 showed result of the effects of land use on aggregates associated and total organic carbon. The soil under EP sequestered higher fine particulate carbon (9.95 $g\ kg^{-1}$), intra aggregate carbon (14.03 $g\ kg^{-1}$), silt + clay associated carbon (9.86 $g\ kg^{-1}$), non hydrolazable carbon (13.24 $g\ kg^{-1}$) and total carbon (8.8 $g\ kg^{-1}$) than other land use/cover in all the carbon pools. Soils under FL which sequestered least amount of non-hydrolysable carbon (2.68 $g\ kg^{-1}$), implied that, carbon stored under this land use have low resident time, as such not sustainable for climate change mitigation. This confirm Lawal (2013) who also reported significant higher soil carbon under Eucalyptus plantation after *Tamarindus indica* in soils of Afaka forest. Similarly, Sainepo *et al.* (2018) reported significantly higher total organic carbon; particulate organic carbon and mineral/ Intra aggregate particulate organic carbon under shrub lands than soils under grassland, agricultural land and bare surface. They reported that soils under shrub land significantly recover above and below ground biomass more than soils under agricultural and grassland. Mganga *et al. (2011) also reported that higher TOC in shrub land was due to high carbon inputs and the protective cover for SOC loss offered by the shrub land compared to grassland and agricultural lands in soils of southern Kenya.*

Lower carbon pool under GP and TP plantation could be attributed to continuous deforestation and bush burning common in the area. Also, Teak is reported to immobilize 80 - 90% of its annual uptake of nutrients, which results in depletion of soil nutrients over time (Nwoboshi, 1984). Tillage, low plant cover and nutrient mining through crop production could be responsible for low carbon pool under FL. This corroborates Lawal (2013) who also reported significant low carbon under Teak plantation which was attributed to slow mineralization of Teak litter. Further, Sainepo *et al.* (2018) reported that agricultural land had lower particulate organic carbon than other land uses. Lower labile carbon under agricultural land was due to its fragile nature that is highly dependents on management practices. Soil disturbance (tillage practices) are known to break down macro aggregate that expose labile carbon to high rate of decomposition and mineralization leading to carbon loss (Bayer *et al., 2006;* McLauchlan, 2006).

The higher carbon content soils in EP relative to other land use could be explained in terms of slow decomposition of litter, litter quality and soil fauna activities. Lorenzo and Welington (2018) submitted that soil organic carbon stock under Pinus and Eucalyptus plantations were two times higher than soils under native Cerrado forest. Higher carbon content and C:N ratios in soils under EP were responsible for higher organic material accumulation than in other land uses. Many authors had reported higher carbon stock in forested soils under Eucalyptus compared to native forest soils (Neufeldt *et al.*, 2002; Maquere *et al.*, 2008; Lorenzo and Welington, 2018). Further, Aweto and Moleele (2005) also reported that Eucalyptus plantations are not efficient in cycling nutrient due to its higher C:N ratio, with slow rate of decomposition and mineralization and results to low nutrient release (Castro-Diez *et al.,* 2011; Bernhard-Reversat and Schwartz, 1997). Eucalyptus plantation releases an allelochemical into the soil system during decomposition to inhibit the growth of other tree species around them and those planted in succession (FAO, 2011; Ruwanza *et al.,* 2014; Albert, 2016).

Generally, soil organic carbon in the surface soils decreased significantly with increasing soil depth for all aggregates associated carbon (Fine particulate, intra aggregate particulate, silt plus clay and non-hydrolysable carbon) (Table 3). Significantly ($P < 0.05$) higher SOC in top soils was attributed to higher litter deposition that allow accumulation of soil organic matter. This is in line with Hubber *et al.* (2001) who reported high accumulation of organic matter due to significant rate of decomposition of plant litter in surface soils. This also corroborates the report of Sainepo *et al.* (2018) and Sahoo *et al.* (2019) who submitted higher organic carbon over surface soils than subsoils and decreases with soil depth and were ascribed to high deposition of plant litter leading to organic matter accumulation in forest floor.

Table 3: Effect of Land use on aggregates associated and total organic carbon

Locations	Labile carbon	Intra aggregate particulate	Silt plus clay	Non hydrolysable carbon	Total organic carbon
EP	9.95a	14.03a	9.86a	13.24a	8.8a
FL	2.98b	5.89b	5.67ab	2.68b	3.44b
GP	1.98b	3.09b	4.90b	3.62b	3.76b
MP	4.73ab	5.48b	5.48ab	3.62b	4.7b
NP	4.20ab	5.72b	6.24ab	3.85b	4.02b
TP	3.03b	3.68b	3.38b	3.03b	4.5b
P-value	0.2937	0.2646	0.4148	0.1826	0.0123
LOS	NS	NS	NS	NS	**
SE+	2.2652	2.785	1.6819	1.650	0.9771
Depth					
Surface	9.071a	11.696a	11.317a	9.970a	9.09a
Subsoils	1.517b	3.252b	3.009b	2.520b	2.18b
P-value	0.0097	0.018	0.0007	0.0450	0.0001
LOS	**	**	***	*	***
SE+	1.6018	1.9693	1.1893	2.4959	0.6909

Note: EP = Eucalyptus, FL = Farmland, GP = Gmelina, MP = Mixed Plantation, NP = Natural Plantation, TP = Teak Plantation, Means followed by similar latter are not significant at 5% level.

Generally, higher organic matter concentration and higher mineralization rate are usually associated with macro aggregate size fractions that are less protected (Liao *et al.,* 2006; Gemma *et al.,* 2017), while organic matter associated with micro aggregates are more protected chemically and recalcitrated biochemically (Jastrow, 1996, Six *et al.,* 2000; Gemma *et al.,* 2017). Further, labile carbon under all the land use/cover types were higher than non labile carbon to imply constant supply of easily decomposable litter in the soil system annually. This is in line with Sahoo *et al.* (2019) who reported higher content of labile carbon than non labile carbon.

3.3 Relationships between soil aggregate and carbon pools

The study showed that total carbon significantly ($P < 0.01$) correlated positively with all carbon pools and silt plus clay content and negative correlation with MWD (Table 4). Mean weight diameter significantly ($P < 0.01$) correlated with large macro aggregate and negatively correlated with all other aggregate fractions and carbon pools. This showed that large macro aggregate contributes significantly to MWD under the land uses as compared with soil carbon pools. Soil aggregate stability is a factor of soil texture, flocculation and binding of soil particles by clay, carbonate, organic matter, root exudates and organisms (Bronick and La, 2005; Six *et al., 2004). Mean weight diameter which positively correlated with large macro aggregate and negatively with all other aggregate fractions was similar to the findings of Shahmir et al. (2017) who reported significant correlation between large aggregate fraction and MWD as compared with small and micro aggregates. The result of this study is in conformity with report of Liu et al. (2014) and Wang et al. (2016) who reported significant relationships between MWD and large aggregate fractions.* The negative relationship between MWD and soils carbon pools implies that SOC does not contribute significantly to aggregate formation under the land uses. This is in line with Shahmir *et al.* (2017) who also observed a negative relationship between SOC and

Table 4: Correlation coefficient between organic carbon pools under different Land uses.

	LC	IAP	SiCl	NHC	TC	LMA	SMA	MA	Si+Clay	MWD
LC	1									
IAP	.979**	1								
SiCl	.903**	.904**	1							
NHC	.934**	.941**	.820**							
TC	.928**	.919**	.854**	.969**	1					
LMA	-.331	-.324	-.333	-.450	-.405	1				
SMA	.043	.065	.083	.217	.193	-.882-**	1			
MA	.600**	.564*	.570*	.621**	.580*	-.807-**	.441			
Si+Clay	.458	.402	.367	.372	.285	-.485-*	.075	.763**	1	
MWD	-.418	-.387	-.404	-.528-*	-.522-*	.912**	-.704**	-.886**	-.492-*	1

LC = labile carbon; IAP = Intra aggregate particulate; SiCl = Silt plus Clay; NHC = Non Hydrolazable Carbon; TC = Total carbon; LMA = Large macro aggregate; SMA = small macro aggregate; MA = Micro aggregate, Si+Clay = Silt plus clay aggregates.

**. Correlation is significant at the 0.01 level. *. Correlation is significant at the 0.05 level (2-tailed).

4.0 Conclusion

Soils under EP were higher in micro aggregate, silt+clay aggregates, MWD and all the carbon pools than the other land use/cover, while soils under GP, TP and FL recorded the least values. Surface soils were higher in all the carbon pools than subsoils. Labile carbon fraction was also higher than non-labile carbon in all the land use types. Total C significantly correlated with all carbon pools and silt plus clay content and negatively correlates with MWD. Among all the land use/cover, soils under EP, NP and MP are best suited for sustainable land management and climate change mitigation, while TP, FL and GP land use/cover were the worst due to low aggregation and carbon sequestration. Indiscriminate lumbering, setting of forest on fire and continuous conversion of forest to farmland were factors responsible for low soil aggregation and carbon sequestration under the land use/cover types.

5.0 Recommendations

Management options recommended for Afaka forest reserve include the following: restriction of indiscriminate lumbering. Selective lumbering of matured trees should be adhered to under all the land use/cover. Hunters and farmers should be cautioned about setting the forest on fire which is one of the major causes of land degradation under all land uses/cover most especially under TP and GP. In addition, to enhance SOC content/soil carbon pool in the affected land use/cover, the incorporation of residue back into the soils after harvest rather than burning the residues is recommended under farmland. Further, application of farmyard manure and use of organo-mineral fertilizers as well as planting leguminous crops on the farmland would be required.

References

Abaje, I.B., Sawa, B.A., Iguisi, E.O. and Ibrahim, A.A. (2015). Impacts of climate change and adaptation strategies in rural communities of Kaduna State, Nigeria. *Ethiopian Journal of Environmental Studies and Management,* 9 (1), 97 – 108.

Albert K. M. (2016) Effects of Eucalyptus Plantation on Soil Physico-Chemical Properties in Thiririka Sub-Catchment, Kiambu County, Kenya. MSc. Thesis in the School of Pure and Applied Sciences of Kenyatta University.

Anikwe, M.A.N (2010) Carbon storage in soils of Southeastern Nigeria under different management practices. *Carbon Balance and Management*, 5:5:1-7 http://www.cbmjournal.com/content/5/1/5.

Aweto, A. O., and Moleele, N. M. (2005). Impact of *Eucalyptus camaldulensis* plantation
On an alluvial soil in south eastern Botswana. *International Journal of Environmental Studies.* 62(2): 163–170.

Bayer C, Martin□Neto L, Mielniczuk J, Pavinato A, Dieckow J. (2006) Carbon sequestration in two Brazilian Cerrado soils under no□till. *Soil Tillage Res.; 86(2):237–45*

Beare, M.H., Hendrix, P.F. and Coleman, D.C. (1994). Water Stable Aggregates and Organic Matter Fractions in Conventional and no Tillage Soils. *Soils Science Society American Journal. 58: 777-786.*

Bernhard-Reversat, F., and Schwartz, D. (1997). Change in lignin content during litter decomposition in tropical forest soils (Congo): comparison of exotic plantations and native stands. Renderings of the Academy of Sciences Series. *IIA-Earth and Planetary Science,* 325: 427–432.

Bronick, C.J.; and Lal, R. (2005) Soil structure and management: A review. *Geoderma*, *124*, 3–22.

Castro-Díez P., Fierro-Brunnenmeister N., González-Muñoz, N., and Gallardo, A. (2011). Effects of exotic and native tree leaf litter on soil properties of two contrasting sites in the Iberian Peninsula. Plant and Soil, 350: 179 – 191.

Christensen, B.T. (1992). Physical fractionation o soil and organic matter in primary particle size and density separates. Soil Science. 20: 2 – 90.

FAO (2011). *Eucalyptus* in East Africa: Socio-economic and environmental issues (No. 46/E) (pp. 1–42). Rome, Italy.

Gemma T., Rogier P. O., Schulte, G. J., Lanigan, K. A., Byrne, B. R., Iolanda S., Johan S. and Rachel E. C., (2017) *Clay illuviation provides a long term sink for C sequestration in subsoils*. Scientific Reports www.nature.com 7:45635 | DOI: 10.1038/srep45635.

Haynes RJ. (2005). Labile organic matter fractions as central components of the quality of agricultural soils. *Adv Agron*. 85: 221–268.

Hubbert, K.R., Graham, R.C. and Anderson, M.A. (2001). Soil and weathered bedrock. Components of Jeffrey pine plantation substrate. *Soil Science Society American Journal.* 65: 1255 – 1262.

Jastrow, J.D. (1996) Soil Aggregate Formation and the Accrual of Particulate and Mineral-Associated Organic Matter. Soil Biology & Biochemistry, 28, 665-676. https://doi.org/10.1016/0038-0717(95)00159-X.

Keay RWJ (1959): *An Outline of Nigerian Vegetation*, 3rd edn. Government Printer, Lagos.

Kowal, D. and D.J. Knabe (1972). *An Agro Climatological Atlas of the Northern State of Nigeria.* Ahmadu Bello University Press, Zaria, Nigeria.

Lal, R. (2005) Forest soils and carbon sequestration. *Forest Ecology and Management*. 220(1): 242–258.

Lawal H.M., Ogunwole, J.O. and Uyovbisere, E.O. (2012) Reciprocal Relationships between Aggregate Stability and Organic Carbon Characteristics in A Forested Ecosystem of Northern Nigeria**.** *Tropical and Subtropical Agroecosystems. 15: 481 – 488.*

Lawal, H.M. (2013) Soil Aggregate Fractions and Organic Carbon Pools as Influenced by Tree Diversity in Forest Reserve of Semi-Arid Nigeria. *Tropical and Subtropical Agroecosystems*, 16 (2013): 515 – 523.

Liao, J.D., Boutton, T.W. and Jastrow, J.D. (2006) Organic Matter Turnover in Soil Physical Fractions Following Woody Plant Invasion of Grassland: Evidence from Natural 13C and 15N. *Soil Biology & Biochemistry,* 38, 3197-3210. https://doi.org/10.1016/j.soilbio.2006.04.004.

Liu, M.Y.; Chang, Q.R.; Qi, Y.B.; Liu, J.; Chen, T. (2014) Aggregation and soil organic carbon fractions under different land uses on the tableland of the Loess Plateau of China. *CATENA*. *115*, 19–28.

Lorenzo M. L. and Welington D (2018). Effects of Eucalyptus and Pinus Forest Management on Soil Organic Carbon in Brazilian Wooded-Savanna. Forest Biomass and Carbon. Chapter 24 pp. 61-81 http://dx.doi.org/10.5772/intechopen.72684

Maquere V, Laclau JP, Bernoux M, Saint-Andre L, Gonçalves JLM, Cerri CC, Piccolo MC, Ranger J. (2008) Influence of land use (savanna, pasture, Eucalyptus plantations) on soil carbon and nitrogen stocks in *Brazil. European Journal of Tropical Science.**59**:863-877*

McLauchlan K. (2006). The nature and longevity of agricultural impacts on soil carbon and nutrients: a review. *Ecosystems.* 9: 1364–1382.

Mganga KZ, Musimba NK, Nyariki DM, Nyangito MM, Ekaya WN, Muiru WM, Mwang'ombe AW. (2011.) Different land use types in the semi□arid range□ lands of Kenya influence soil properties.

Nelson D.W and Sommers, L.E (1982): Total Carbon, Organic Carbon and Organic Matter. In page, A.: Miller, R.H and Keeney, D.R (eds) Methods of Soil Analysis II American Society of Agronomy Madison NY 539-579.

Neufeldt H., Resck D.VS., Arzaya M.A. (2002) Texture and land-use effects on soil organic matter in Cerrado Oxisols, Central Brazil. Geoderma. **107**:151-164

Nwoboshi, L.C., (1984). Growth and nutrient requirements in a teak plantation age series in Nigeria. II Nutrient accumulation and minimum annual requirements. *Sci., 30(1): 35-40.*

Odunze A. C. (2015) Soil Conservation for Mitigation and Adaptation to a Changing Climate: Sustainable Solutions in the Nigerian Savanna Ecology. *International Journal of Plant and Soil Science* 8(4): 1-12; ISSN: 2320-7035. www.sciencedomain.org

Odunze A. C., Musa Y. D., and Abdulkadir A. (2017) Soil Organic Carbon Concentrations and Stocks under Maize/Legume Cropping System in Alfisols of a Savanna Zone, Nigeria. *British Journal of Applied Science & Technology*. 21(1): 1-12; ISSN: 2231-0843.

Paul, E.A., Morris, S.J., Six J., Paustian, K., and Gregorich, E.G. (2003). Interpretation of soil carbon and Nitrogen dynamics in Agricultural and Afforested soils *Soil Science Society of America Journal 67: 1620 – 1628.*

Poeplau, C. and Don, A., (2013). Sensitivity of soil organic carbon stocks and fractions to different land-use changes across Europe. *Geoderma* 192, 189–201.

Raji B.A, Ogunwole J.O. (2006): Potential of soil carbon sequestration under various land use in the sub-humid and semi-arid savanna of Nigeria, Lessons from long term experiments. *Int. Journal of Soil Science*, 1:33-43.

Ruwanza, S., Gaertner, M., Esler, K. J., and Richardson, D. M. (2014). Allelopathic effects of invasive *Eucalyptus camaldulensis* on germination and early growth of four native species in the Western Cape, South Africa. *Southern Forests: Journal of Forest Science. 1, 1-15*

Sahoo UK, Singh SL, Gogoi A, Kenye A, Sahoo SS (2019) Active and passive soil organic carbon pools as affected by different land use types in Mizoram, Northeast India. PLoS ONE 14(7): e0219969. https://doi.org/10.1371/journal. pone.0219969

Sainepo, M.B., Gachene, C.K., and Karuma, A. (2018) Assessment of soil organic carbon fractions and carbon management index under different land use types in Olesharo Catchment, Narok County, Kenya. Carbon Balance Manage. 13:4 https://doi.org/10.1186/s13021-018-0091-7.

Shahmir Ali Kalhoro, Xuexuan Xu, Wenyuan Chen, Rui Hua, Sajjad Raza and Kang Ding (2017) Effects of Different Land-Use Systems on Soil Aggregates: A Case Study of the Loess Plateau (Northern China) *Sustainability. 9; 1349 doi: 10.3390/su9081349.*

Six, J., Paustian, K., Elliott, E.T. and Combrink, C. (2000) Soil Structure and Organic Matter: I. Distribution of Aggregate-Size Classes and Aggregate-Associated Carbon. *Soil Science Society of America Journal*, 64, 681- 689. https://doi.org/10.2136/sssaj2000.642681x.

Six, J.; Bossuyt, H.; Degryze, S.; Denef, K. (2004) A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. *Soil Tillage Res. 79*, 7–31.

Sollins P, Homann P, Caldwell BA. (1996). Stablization and destabilization of soil organic matter: mechanisms and controls. *Geoderma.* 74(1): 65–105.

Tan, Z.X., R. Lal, C. Izaurralde and W.M. Post. (2004). Biochemical Protected Soil organic carbon at the North Appalachian Experimental watershed. *Soil Science*. 169: 1-10.

Van Bavel, C.H.M. (1950). Mean weight diameter of soil aggregates as a statistical index of Aggregation, *Soil Science society of America Journal*, 14:20-21.

Wang, J.G.; Yang, W.; Yu, B.; Li, Z.X.; Cai, C.F.; Ma, R.M. (2016) Estimating the influence of related soil properties on macro- and micro-aggregate stability in ultisols of south-central China. *CATENA*, *137*, 545–553.

Wiesenberg GLB, Dorodnikov M, Kuzyakov Y. (2010) Source determination of lipids in bulk soil and soil density fractions after four years of wheat cropping. *Geodarma.* 156: 267–277.

Wilson, B.R., Growns, I., Lemon, J., (2008). Land-use effects on soil properties on the north-eastern slopes of New South Wales: implications for soil condition assessment. *Australia Journal of Soil Research*. 46, 359–367.