Soil Carbon Distribution in Three Land Uses of Gambari Forest Reserve Area, Oyo State

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Abstract

Soil adsorptive property is considered for mitigation of climate change in the terrestrial ecosystem. However, there are inconsistent findings on the contribution of aggregate sizes to carbon sequestration in soil depths. Inappropriate land-use practices cause increasing greenhouse gases in the atmosphere. Detail estimation of carbon associated with soil aggregates in different land-uses is required to identify land-use practice that promotes carbon accumulation. Therefore, the objective of the study was to investigate distribution of organic carbon associated with the soil aggregate sizes in selected land-uses. Three (30 m x 30 m) sample plots were established randomly in each of Natural Forest (NF), Plantation Forest (PF) and Cultivated Land (CL). Soil core samples were collected at 0-15, 15-30 and 30-45 cm depths using steel soil corers). Soil core samples were oven-dried at 105°C and bulk densities were computed. Oven-dried soil sample of 100 g was separated into five aggregates (>2, 2-1, 1-0.5, 0.5-0.05 and <0.05 mm) using the dry sieve procedure. Each aggregate (10 g) was heated in Muffle furnace at 500°C for 4 hours for soil carbon estimation. Aggregate sizes >2mm dominated NF and PL while 0.05 mm dominated CL. There was no significant difference in the distribution of aggregate sizes of NF and CL, except PL. The three land-use practices have the same proportion of aggregate 1-0.5mm at topsoil. Macro- and micro-aggregates influence soil carbon content in natural forest and plantation forest, respectively. Depth and land-use change caused re-distribution of carbon on soil aggregate sizes.

Keywords: Carbon sequestration, Soil organic carbon, soil aggregates, land-use types, climate change mitigation

Introduction

The depletion of soil organic matter through inappropriate land use practices could increase greenhouse gases in the atmosphere. The present global warming issue is due to high concentration of greenhouse gases, especially carbon dioxide (Dhillon and Van Rees, 2017). Irregularity in climatic patterns is caused by global warming and has been described as one of the adverse environmental issues (Zhang and Liu, 2012). Climate change is causing extreme weather conditions such as flooding, wildfire and severe drought in various part of the world. Tillage of land and other agricultural activities are considered to be a major source of greenhouse gases (Six *et al.*, 2000 and Dhillon and Van Rees, 2017) and consequently, less effective for carbon sequestration when compared with natural and plantation forests because of soil disturbance (Six et al., 2000 and Dhillon and Van Rees, 2017). However, Bajracharya *et al.*, (1998) highlight that tillage methods have no significant effects on carbon stabilization but intensity of cultivation that causes decline in soil organic carbon and evolving of carbon dioxide.

Land use practices that conserve or increase soil organic carbon are good option for carbon sequestration. Consequently, adoption of efficient land use practices is essential to ameliorate severe effects of climate change because small change in the carbon reservoir may have large effect on carbon cycle. Detailed understanding of effects of land uses on carbon associated with soil aggregates is required in order to identify those practices that promote net carbon gain.

Soils are major carbon reservoir in the terrestrial ecosystem. Many studies on soil carbon dynamics were restricted to upper 10-20 cm depth of mineral soil (Alvarez *et al.*, 2014 and Herold *et al.*, 2014 and Wambsganss *et al.*, 2017) but large proportion of stable soil carbon is found beyond 20 cm depth (Fang *et al.*, 2015). Therefore, some studies reported high carbon stabilization and sequestration capacity beyond 20 cm depth (Fang *et al.*, 2015 and Rumpel and Kogel-Knabner, 2011) and other indicated high carbon stock in the surface soil <10 cm (Wambsganss *et al.*, 2017 and Alvarez *et al.*, 2014). However, there have been inconsistent findings on carbon stabilization capacity of soil aggregate sizes at shallow soil depth. Six *et al.* (2000) and Park and Smucker (2005) stated that carbon associated with micro-aggregates is the basic unit of soil carbon stock and macro-aggregate is formed from aggregation of micro-aggregates. Therefore, a detailed understanding of carbon sequestration mechanisms require assessment of distributions and patterns of carbon associated with aggregate sizes in soils.

It has been stated that the mechanisms for aggregate formation and conditions of carbon stabilization at surface (<20 cm depth) and deep soil (>30 cm depth) layers may be different (Rumpel and Kogel-Knabner, 2011 and Fang *et al.*, 2015) and hence, organic carbon sequestration of surface and deep soil layers may be driven by different mechanisms. Chemical adsorption and physical aggregation by occlusion are most recognized stabilization mechanisms of soil carbon (Sollin *et al.*, 1996 and Baldock and Skjemstad, 2000). Therefore, knowledge of response of carbon associated with aggregate fractions to land use change will unravel mechanisms responsible for carbon stabilization at subsoil (15-30 cm) and deep soil (30-45 cm) depths of Gambari Forest Reserve. The amount and distribution of soil carbon associated with aggregate sizes can be used to evaluate aggregation mechanism under different land uses and how soil depth affects distribution of carbon to depth of 45 cm. This information will improve basic understanding on the mechanisms that cause soil aggregation and carbon stabilization in Gambari Forest Reserve. The carbon distribution and pattern in selected land use types could be effectively compared since they are located on the same soil type and series with the same isothyte.

Furthermore, Chacon *et al.*, (2015) stated that high inputs of organic matter in cultivated soil may cause higher organic carbon content than natural forest. Conversely, large input of organic matter may not cause high stabilization of organic carbon in fine soil particle (Feng *et al.*, 2013) under the same climate and soil type (Sausen *et al.*, 2014) and this indicates the influence of additional factors that are completely unidentified, thus, understanding the factors responsible for this phenomenon require investigation.

Gambari Forest Reserve is one of the first forest reserves in Nigeria and covers 100,000 hactares (Bakare, 1989) of Alfisol of Southwestern Nigeria (Mackay, 1923 and Mcgregor, 1934). The reserve was delineated into natural forest, plantation forest and Taungya research plots by government of the then Western region (Bakare, 1989). Improved knowledge of the distribution of aggregate sizes and associated carbon among different land use types will provide understanding on land use practice that enhances optimum carbon storage in Alfisol by quantifying the soil carbon sink capacity of the different land use types. Soil carbon and distribution in different land use types on Alfisol is limited.

Therefore, the objective of the study was to investigate the distribution of organic carbon associated with aggregate sizes in three land use types with a view to elucidating management practice that optimize net carbon sequestration. Therefore, these hypotheses were tested; (i) soil carbon associated with aggregate sizes is significantly different among the three land use types, (ii) soil carbon stock is significantly different among the three land use types.

Materials and Methods

Soil samples were collected at Gambari Forest Reserve Area of Oyo state, Nigeria. Gambari Forest Reserve is located between Latitude 7º 25´and 7º 55´N and Longitude 3º 53 and 3º 69´ E (Figure 1). Gambari Forest Reserve is one of the first forest reserves established in Nigeria and it covers a total land area of 17984 ha. The reserve is delineated into natural forest (NF) and plantation forest (PF). Natural Forest (NF) is estimated as 10 ha. Dry and wet seasons are experienced in the reserve. Dry season lasts for three months (December-February) while rainy season is nine months. The average annual rainfall is about 1150 mm and average annual temperature is about 26.40°C (Akinyemi, 1998). Monthly maximum temperature is 31.90°C in January and 20.20°C in June with a Relative Humidity range of 83% in June to September and 75% in December to January. The soil is Alfisol (Egbeda series) and derived from basement complex rock overlain by crystalline rock of in-differentiates of gneiss, quartz and schist (Mackay, 1923 and Mcgregor, 1934). The topsoil is free drainage with good base accumulation.

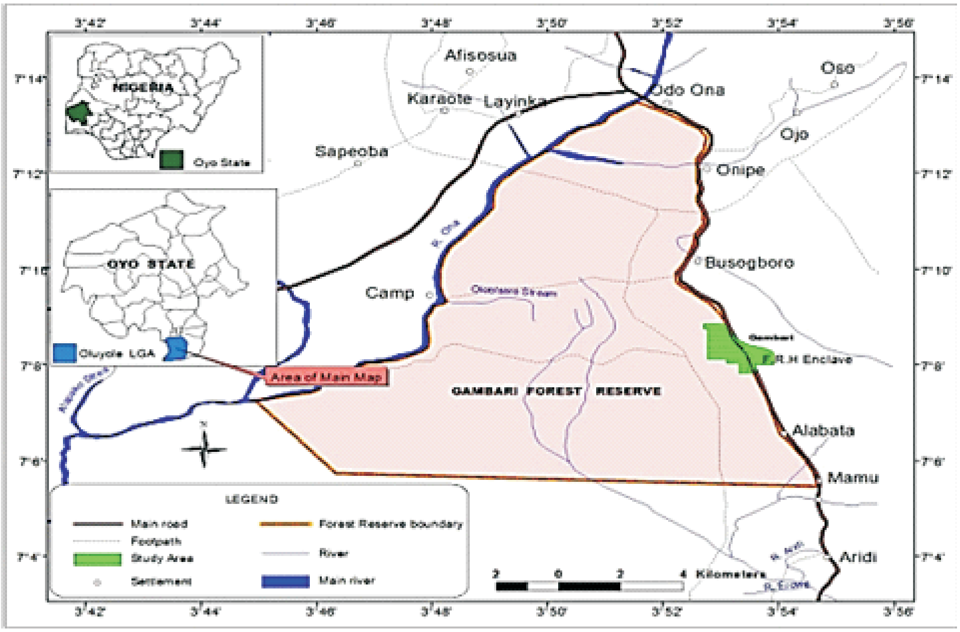

Figure 1: Map of the study area

Methods of data collection

Reconnaissance survey was conducted in Gambari forest Reserve and Natural Forest (NF), Plantation Forest (PF) and Cultivated Land (CL) were identified. Three (30 m x 30 m) sample plots were randomly established in each of Natural Forest (NF), Plantation Forest (PF) and Cultivated Land (CL). Soil core samples were collected from 8 m x 8 m subplots demarcated at four (4) corners and centre of each plot and soil core samples were taken at 0-15, 15-30 and 30-45 cm depths of subplots, using stainless steel soil cores (volume = 176.78 cm^2). Soil cores sampled were transported to the laboratory in sealed plastic containers so as to preserve the natural structure of the core samples.

Soil bulk density and carbon estimation

The bulk densities of the soil core samples were computed using the core method of Rowell (1994). The initial and final weights of soil core samples were taken before and after oven drying at 105°C to a constant weight. Soil bulk densities were computed by dividing mass of oven-dried soil sample by the volume of the core.

Furthermore, oven-dried soil core samples were separated into aggregate fractions using dry sieve method of Brogowski and Kwasowski (2012). Oven-dried soil core sample of 100 g was placed on the top of a stack of four sieves and sieved into five soil aggregate-size (>2, 2-1, 1-0.5, 0.5-0.05 and <0.05 mm) by agitating for one minute with sieve shaker. Dry aggregates remaining on each sieve was collected and weighed. Therefore, five soil aggregate-size (>2, 2-1, 1-0.5, 0.5-0.05 and <0.05 mm) were obtained and each was collected inside transparent polyethylene sample bags for carbon analysis.

Carbon concentration of soil aggregates was determined using the method of Soil and Plant Analysis Council (1999) and Schumacher (2002). An aggregate fraction of 10 g weighed heated in Muffle furnace at 500^{o}C for 4 hours consistently and cooled in a desiccator after which the final weight was taken. The difference in weight is calculated as the amount of carbon loss. Carbon concentration of bulk soil was also determined for topsoil (0-15 cm), subsoil (15-30 cm) and deep soil (30-45 cm) for calculation of soil carbon stock of these soil depths.

Soil carbon stock

Soil carbon stock was calculated as expressed:

Soil Carbon Stock (Mg/ha) = SCC $\times \alpha$(hectare) $\times$BD $\times$ D $\times$ G

Where,

M = soil carbon stock (Mg/ha)

α = constant to adjust for area (hectare=1.0×10^{4}cm^{3})

BD = Bulk density (g/cm^{3})

SCC = Soil carbon concentration (g/kg)

D = Soil depth (15cm)

G = relative amount of gravel (>2mm, %)

Carbon stratification ratio

The stratification ratio of soil carbon (SR) = carbon stock of the upper layer divided by the carbon stock of adjacent layers (Franzluebbers, 2002)

Data analysis

Comparison of carbon concentration associated with aggregate sizes (>2, 2-1, 1-0.5, 0.5-0.05 and <0.05 mm) of each soil depth (0-15 cm or 15-30 cm or 30-45 cm) among land use types (Natural Forest, Plantation Forest and Cultivated Land) was carried out Analysis of variance. A significant threshold of α 0.05 was fixed for Two-Way Analysis of Variance using General Linear model of IBM SPSS Statistics Editor. All statistical analyses were computed using the univariate of General Linear Model of SPSS. The mean separation was done using Duncan Multiple Range Test (DMRT).

Results

Soil bulk density at different depths

Soil bulk density increased with increase in depths in the three land use types (Table 1). Cultivated Land (CL) had the highest bulk density (1.58 g/cm^{3}) at 30-45 cm soil depth while Natural Forest (NF) had the lowest bulk density (1.05 g/cm^{3}) at 0-15 cm soil depth (Table 1). The values of soil bulk density was significantly different among the three land use types ($p \leq 0.05$). The mean separation test showed that soil bulk densities of Natural Forest (1.70 g/cm^{3}) was significantly higher than Cultivated Land (1.38 g/cm^{3}) and Plantation Natural Forest (1.30 g/cm^{3}) (Table 1).

The values of soil bulk density of

topsoil (0-15 cm depth) was significantly different among the three land use types ($p \leq 0.05$). Bulk density of topsoil (0-15 cm depth) of Plantation Forest (1.29 g/cm^3) and Cultivated Land (1.35 g/cm^3) were significantly higher than in Natural Forest (1.05 g/cm^3). Conversely, bulk density of subsoil (15-30 cm depth) of Cultivated Land (1.58 g/cm^3) was significantly higher than Plantation Forest (1.30 g/cm^3) and Natural Forest (1.41 g/cm^3). Also, bulk density of deep soil (30-45 cm depth) of Cultivated Land (1.58 g/cm^3) was significantly higher than Plantation Forest (1.53 g/cm^3) and Natural Forest (1.52 g/cm^3). Therefore, bulk density of Cultivated Land was significantly higher than Plantation and Cultivated Land in the three soil depths.

Table 1. Soil bulk density (g/cm^3) of soil depths in natural forest, plantation forest and cultivated land of Gambari Forest Reserve

Sampling depth (cm)	Natural forest	Plantation forest	Cultivated land
0-15	1.05±0.28aA	1.29±0.16bA	1.35±0.14bA
15-30	1.41±0.17bA	1.30±0.15aA	1.42±0.17bA
30-45	1.52±0.14aA	1.53±0.10aA	1.58±0.24bA
Mean	1.70±0.29a	1.30±0.15b	1.38±0.15b

Means with different lowercase letters along a row are significantly different at $p<0.05$ (DMRT)
Means with different uppercase letters along a column are significantly different at $p<0.05$ (DMRT)

The deep soil and subsoil contained the highest and lowest soil carbon stock, respectively, in Natural Forest and Plantation Forest. Plantation Forest and Cultivated Land contained the highest (4.66 Mg/ha) and the lowest (4.14 Mg/ha) soil carbon stock at 45 cm soil depth, respectively. Conversely, soil carbon stock decreased with increase in soil depth in Cultivated Land (Table 2). Soil carbon stratification ratio of Natural Forest, Plantation Forest and Cultivated Land ranged from 1.09 to 0.79, 1.07 to 0.83 and 1.76 to 1.03, respectively. Carbon stock was significantly different among soil depths of Natural Forest, Plantation Forest and Cultivated Land ($p \leq 0.05$). The carbon stocks of topsoil (1.50 Mg/ha) and subsoil (1.37 Mg/ha) were significantly lower than deep soil (1.72 Mg/ha) in Natural Forest. In Plantation Forest, carbon stocks of deep soil (1.71 Mg/ha) was significantly higher than subsoil (1.42 Mg/ha) and topsoil (1.53 Mg/ha). While in Cultivated Land, carbon stocks of topsoil (1.96 Mg/ha) was significantly higher than deep soil (1.07 Mg/ha) and subsoil (1.11 Mg/ha).

The value of carbon stock of topsoil (0-15 cm depth) and deep soil (30-45 cm depth) was significantly different among three land use types ($p \leq 0.05$). The carbon stocks of Cultivated Land (1.96 Mg/ha) was significantly higher than Plantation Forest (1.53 Mg/ha) and Natural Forest (1.50 Mg/ha) at 0-15 cm depth while at deep soil depth carbon stocks of Natural Forest (1.72 Mg/ha) and Plantation Forest (1.71 Mg/ha) were significantly higher than Cultivated Land (1.07 Mg/ha).

The topsoil (0-15 cm depth) had the highest carbon concentration in the three land use types (Table 3), while the subsoil (15-50 cm) had the lowest carbon concentration in Natural Forest and

Plantation Forest. Soil carbon concentration decreased with increase in soil depth in Cultivated Land. Carbon concentration was significantly different among soil depths ($p \leq 0.05$) of Natural Forest and Cultivated Land. The carbon concentration of topsoil (9.70 g/100 g) was significantly higher than subsoil (6.55 g/100 g) and deep soil (7.07 g/100 g) in Natural Forest. Also, carbon concentration of topsoil (9.31 g/100 g) was significantly higher than deep soil (4.72 g/100 g) and subsoil (5.73 g/100 g) in Cultivated Land. Furthermore, carbon concentration in deep soil was significantly different among land use types ($p \leq 0.05$). The carbon concentration of Natural Forest (7.07 g/100 g) and Plantation Forest (7.89 g/100 g) were significantly higher than Cultivated Land (4.72 g/100 g) at deep soil (30-45 cm depth).

Table 2. Soil carbon stock (Mg/ha) of soil depths in natural forest, plantation forest and cultivated land of Gambari Forest Reserve

Sampling depth (cm)	Natural forest	Plantation forest	Cultivated land
0-15	1.50±0.54aA	1.53±0.47aA	1.96±0.59bA
15-30	1.37±0.51aA	1.42±0.31bA	1.11±0.42aB
30-45	1.72±0.37aB	1.71±0.41aB	1.07±0.27bB
Total	4.59a	4.66a	4.14a

Means with different lowercase letters along a role are significantly different at p<0.05 (DMRT)
Means with different uppercase letters along a column are significantly different at p<0.05 (DMRT)

Table 3. Soil carbon concentration (gC/100g of soil) of soil depths in natural forest, plantation forest and cultivated land of Gambari Forest Reserve

Sampling depth (cm)	Natural forest	Plantation forest	Cultivated land
0-15	9.70±2.48aA	9.81±2.30aA	9.31±3.93bA
15-30	6.55±1.58aB	7.85±0.93aB	5.73±2.53bB
30-45	7.07±0.86aA	7.89 ±2.02aB	4.72±0.89bB

Means with different lowercase letters along a role are significantly different at p<0.05 (DMRT)
Means with different uppercase letters along a column are significantly different at p<0.05 (DMRT)

Aggregate size distribution in soil depths of Gambari Forest Reserve

Aggregate size <0.05 mm (31.14 g/100 g) represented the highest proportion of soil by weight, followed by aggregates 1.0-0.5 mm (16.75 g/100 g) and >2.0 mm (15.62 g/100 g) at 0-15 cm depth in Plantation Forest. However, the value of aggregate size >2.0 mm accounted for highest proportion of soil by weight, followed by aggregates 2.0-1.0 mm and 1.0-0.5 mm at 0-15 cm depth in Natural Forest and Cultivated Land (Figure 2). Hence, Plantation Forest had more proportion of aggregates <0.05 mm (31.14 g/100 g) and 0.5-0.05 mm (9.86 g/100 g) than Natural Forest and Cultivated Land at 0-15 cm soil depth. Natural Forest and Cultivated Land contained approximately the same proportion of aggregates 1.0-0.5, 0.5-0.05 and <0.05 mm by weight of soil at 0-15 cm depth. Conclusively, there is no significant difference in aggregate size distribution of Natural Forest and Cultivated Land. The three land use types had approximately the same proportion of aggregate 1.0-0.5 mm at 0-15 cm depth. Therefore, aggregate size <0.05 mm dominated the soil mass of topsoil of Plantation Forest while aggregate size >2.0 mm dominated the soil mass of topsoil of Natural Forest and Cultivated Land. Also, proportion of aggregate >2.0 mm at topsoil of Natural Forest and Cultivated Land was 2.8 times proportion of aggregate >2.0 mm in Plantation Forest (Figure 2). Conversely, the proportion of aggregate <0.05 mm at topsoil of Plantation Forest was approximately 3 times of proportion of aggregate <0.05 mm in Natural Forest and Cultivated Land.

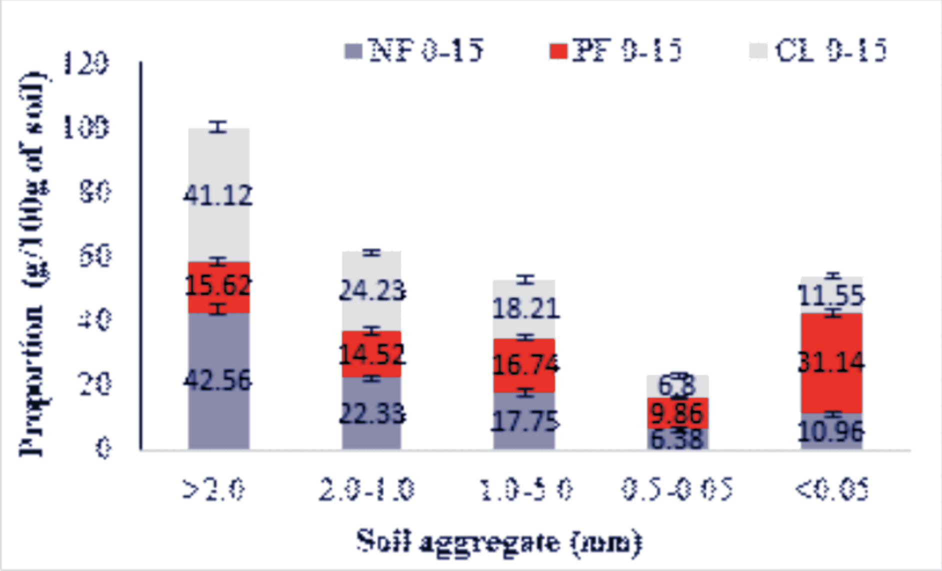

Figure 2. Proportion by weight (g/100 g soil) of aggregates of topsoil (0-15 cm soil depth) in Natural forest, Plantation Forest and Cultivated Land (error bar (SE))

Plantation Forest contained the highest proportion of aggregate <0.05 mm (34.17 g/100 g) of soil by weight, followed by aggregate size >2.0 mm (18.70 g/100 g) and 1.0-0.5 mm (16.12 g/100 g) at subsoil (15-30 cm depth) (Figure 3). Aggregate >2.0 mm represented highest proportion of soil by weight, followed by aggregates 2.0-1.0 mm and 1.0-0.5 mm in both Natural Forest and Cultivated Land. Furthermore, Natural Forest and Cultivated Land contained approximately the same proportion of aggregate size 1.0-0.5, 0.5-0.05 and <0.05 mm at subsoil (15-30 cm depth) (Figure 3). There was no significant difference in the aggregate distribution of Natural Forest and Cultivated Land at subsoil (15-30 cm depth). Aggregate size <0.05 mm dominated the soil mass of subsoil of Plantation Forest and aggregate >2.0 mm dominated the soil mass of subsoil of Natural Forest and Cultivated Land. The proportion of aggregate >2.0 mm of subsoil of Natural Forest and Cultivated Land was 3.2 times the proportion of aggregate >2.0 mm of Plantation Forest. In contrast, proportion of aggregate <0.05 mm of subsoil of Plantation Forest was approximately 4 times the proportion of <0.05 mm of Natural Forest and Cultivated Land.

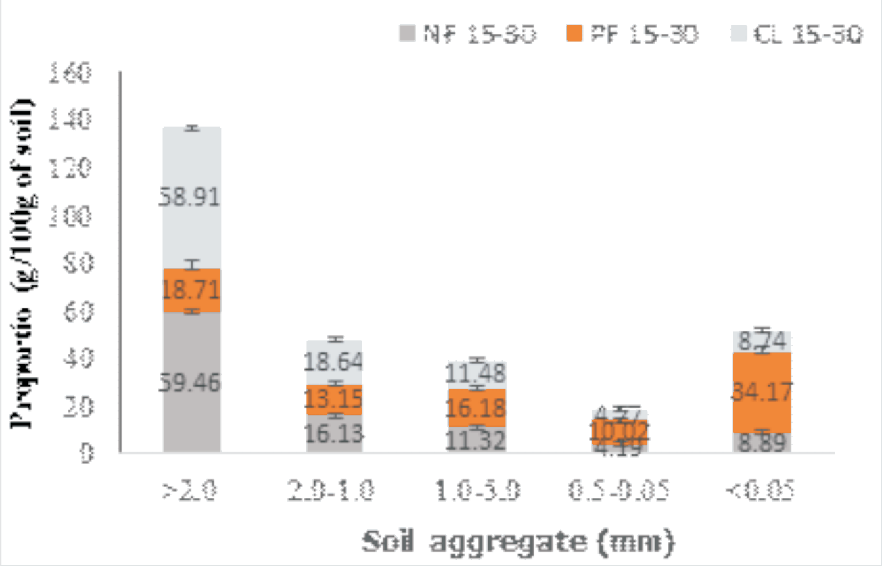

Figure 3. Proportion by weight (g/100 g soil) of aggregates of subsoil (15-30cm soil depth) in Natural Forest, Plantation Forest and Cultivated Land (error bar (SE).

In Plantation Forest, the proportion of aggregate <0.05 mm represented 36.52 g/100 g of dry weight soil, followed by aggregates >2.0 mm (20.46 g/100 g) and 1.0-0.5 mm (16.51 g/100 g) at deep soil (Figure 4). The aggregate size >2.0 mm contained the highest proportion of dry weight soil, followed by 2.0-1.0 mm and 1.0-0.5 mm in both Natural Forest and Cultivated Land. Natural Forest and Cultivated Land contained approximately the same proportion of aggregates 1.0-0.5, 0.5-0.05 and <0.05 mm at deep soil (15-30 cm). There was no significant difference in the aggregate size distribution of Natural Forest and Cultivated Land at deep (30-45 cm depth). Aggregate size <0.05 mm dominated the soil weight of Plantation Forest while aggregate >2.0 mm dominated soil weight of both Natural Forest and Cultivated Land at 30-45 cm depth (Figure 4). The result indicated that proportion of aggregate >2.0 mm of deep soil of Natural Forest and Cultivated Land was 3.0 times of proportion of >2.0 mm of Plantation Forest. In contrast, the proportion of aggregate <0.05 mm in Plantation Forest was approximately 4 times of Natural Forest and Cultivated Land at deep soil 30-45 cm depth.

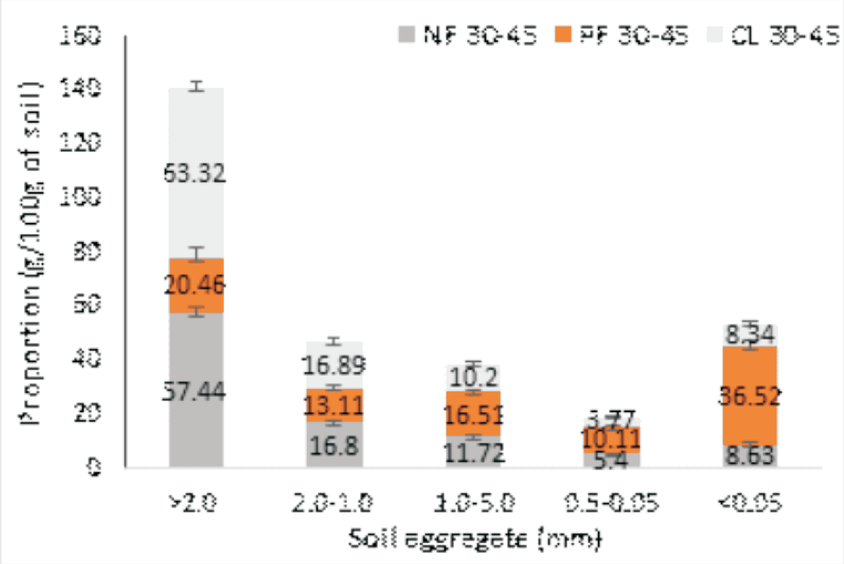

Figure 4. Proportion by weight (g/100 g soil) of soil aggregates of deep soil (30-45cm soil depth) in Natural Forest, Plantation Forest and Cultivated Land (error bar (SE).

Carbon distribution in soil depths of Gambari Forest Reserve

The soil carbon associated with aggregates of topsoil (0-15 cm depth) of Natural Forest was significantly higher than Plantation Forest and Cultivated Land (Figure 5). However, soil carbon associated with aggregates of Cultivated Land was not significantly different from Plantation Forest at topsoil (0-15 cm depth). The aggregate size 2.0-1.0 mm contained highest carbon concentration (11.89 gC/100 g of soil), followed by aggregates >2.0 mm (11.29 gC/100 g of soil) and 1.0-0.5 mm (9.98 gC/100 g) in the topsoil of Natural Forest. Hence, soil carbon associated with aggregates decreased from aggregate 2.0-1.0 mm to <0.05 mm in Natural Forest. The aggregate >2.0 mm contained highest carbon concentration (7.41 gC/100 g), followed by 2.0-1.0 mm (6.91 gC/100 g) and <0.05 mm (6.47 gC/100 g) at topsoil (0-15 cm depth) of Cultivated Land. There was no significant difference in the carbon distribution of aggregates in Plantation Forest and Cultivated Land. Also, aggregates of Cultivated Land contained more soil carbon than aggregates of Plantation Forest at topsoil except for aggregate >2.0 mm which contained similar soil carbon concentration. Therefore, soil carbon associated with aggregates decreased from aggregate >2.0 to <0.5-0.05 mm in Cultivated Land and Plantation Forest. Conclusively, soil carbon associated with aggregates decreased with decrease in aggregate size at 0-15 cm depth, in three land use types.

Soil carbon associated with aggregates of Natural Forest, Plantation Forest and Cultivated Land ranged from 11.29 to 8.41, 7.64 to 4.82 and 7.41 to 5.53 gC/100 g, respectively, at topsoil (0-15 cm depth) (Figure 5). The variation was highest in Natural Forest, followed by Plantation Forest and least in Cultivated Land.

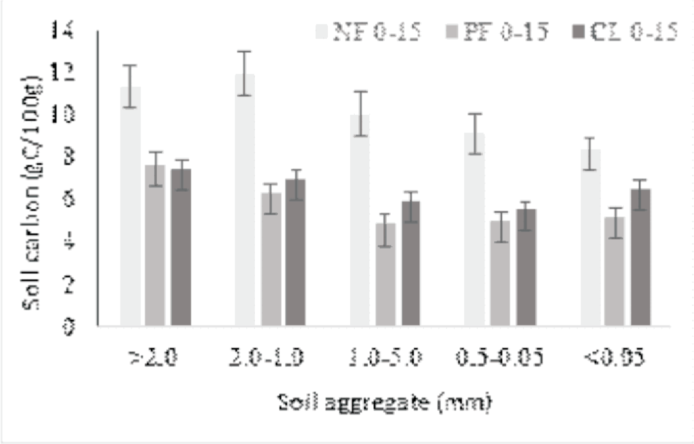

Figure 5. Soil carbon associated with aggregates of topsoil (0-15 cm soil depth) in Natural Forest, Plantation Forest and Cultivated Land **(error bar (SE))**

Carbon concentration was significantly different among the soil aggregates ($p \leq 0.05$) at subsoil (15-30 cm depth). Aggregate of Natural Forest had higher carbon concentration than aggregates of Plantation Forest and Cultivated Land at 15-30 cm soil depth. Soil aggregate 2-1.0 mm contained highest concentration of carbon, followed by aggregate <0.05 mm at 15-30 cm depth of Natural Forest (Figure 6). However, soil aggregate >2.0 mm contained the highest concentration of carbon, followed by aggregate <0.05 mm and 2-1.0 mm at deep soil (15-30 cm depth) in Cultivated Land and Plantation Forest. Soil carbon concentration of aggregates of subsoil (15 – 30 cm depth) ranged from 6.99 to 5.36, 5.64 to 3.53 and 6.03 to 4.37 gC/100 g in Natural Forest, Plantation Forest and Cultivated Land, respectively. Plantation Forest had the highest variation in carbon concentration among the soil aggregates of subsoil, followed by Cultivated Land and Natural Forest.

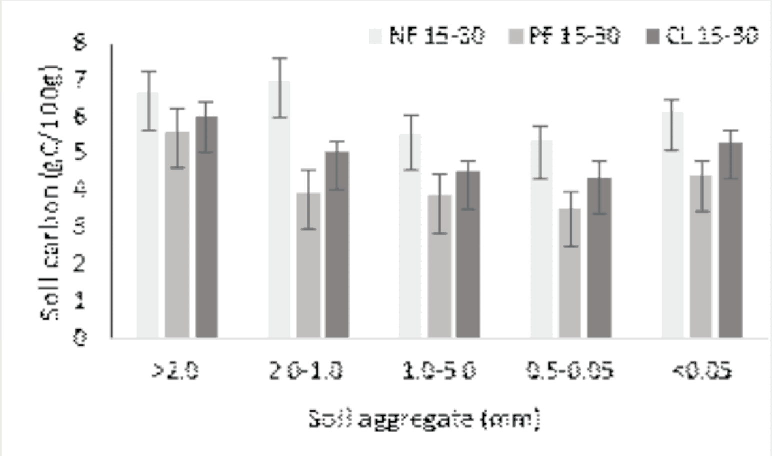

Figure 6. Soil carbon on aggregates of subsoil (15-30 cm soil depth) in Natural Forest, Plantation Forest and Cultivated Land (error bar (SE)

Carbon concentration was significantly different among the soil aggregates ($p \leq 0.05$) and also, carbon concentration associated with aggregate sizes of Natural Forest (6.29 gC/100 g) was significantly different from that of Plantation Forest (3.54 gC/100 g) and Cultivated Land (4.78 gC/100 g) at 30-45 soil depth ($p \leq 0.05$).

Soil carbon in aggregate fractions of deep soil (30-45 cm depth) ranged from 7.51 to 5.41, 4.39 to 2.33 and 5.97 to 3.48 gC/100 g for Natural Forest, Plantation Forest and Cultivated Land, respectively. The Cultivated Land had the highest variation in carbon concentration among the soil aggregates of deep soil, followed by Natural Forest and Plantation Forest (Figure 7).

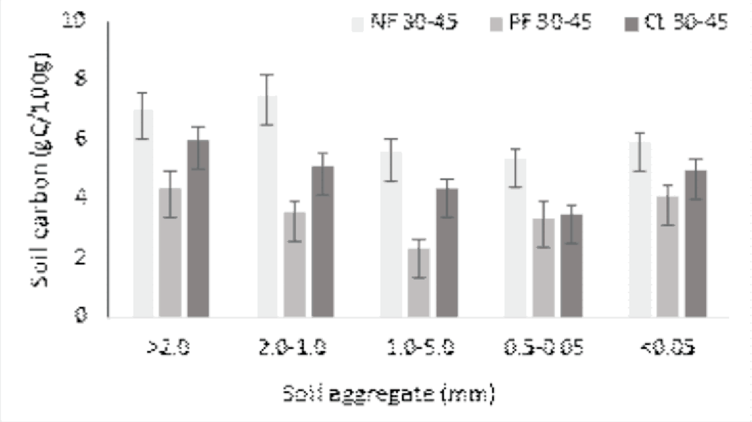

Figure 7. Soil carbon on aggregates of deep soil (30-45 cm soil depth) in Natural Forest, Plantation Forest and Cultivated Land (error bar (SE))

Discussion

Bulk density increased with increase in soil depth of Natural Forest, Plantation Forest and Cultivation Land. Bulk density of Natural Forest was significantly different in the three soil depths. However, bulk density of Cultivated Land was higher than Natural and Plantation Forests in the three soil depths. Carbon stock increased with increase in soil depth of Natural Forest and Plantation Forest but decreased with increase in soil depth of Cultivated Land. Bulk density influence carbon storage by regulating the mobility of dissolved organic carbon through soil matrices (Ostrowska *et al.*, 2010). Natural and Plantation Forests showed natural state of carbon stock distribution because their soils had not been disturbed. Surface soil of Cultivated Land contained more soil carbon concentration and stock than Natural Forest and Plantation Forest. This confirmed the report of Bajracharya *et al.* (1998) that cultivated land under low tillage may have higher soil carbon stock than natural forest in shallow soil depth. Therefore, deep soil layer should be considered for carbon sequestration in Natural Forest and Plantation Forest while topsoil should be considered for carbon sequestration in Cultivated Land of Gambari Forest Reserve. High carbon stock at the deep soil layer of Natural Forest and Plantation Forest and topsoil layer of Cultivated Land could be attributed to deep root litter and surface litter, respectively. Root litters determine the placement of carbon in deep soil depth. The Plantation Forest and Cultivated Land contained the largest and smallest carbon stock at upper 45 cm depth, respectively. Also, high variability of carbon stock at the topsoil can be attributed to exposure and sensitivity of topsoil to environmental factors controlling accumulation of carbon.

There was no significant difference in aggregate size distribution of Natural Forest and Cultivated Land in topsoil, subsoil and deep soil layers. Therefore, tillage had little or no effect on soil aggregate size distribution in the three soil depths. The aggregate size distributions indicated that aggregate >2.0 mm dominated soil mass of Natural Forest and Cultivated Land while aggregate <0.05 mm dominated soil mass of Plantation forest. Therefore, aggregate <0.05 mm was extremely low in the soils of Natural Forest and Cultivated Land. The high percentage of macro-aggregates to 45 cm depth indicates a low potential for soil organic carbon protection because only fine clay sized aggregates (micro-aggregates) protect soil organic carbon (Tisdall and Oades, 1982). Conversely, high proportion of micro-aggregates indicates high potential for soil carbon protection in Plantation Forest.

Soil carbon associated with aggregate fractions increased with increase in aggregate size in soil depths of the three land use types. This result did not support an aggregate hierarchy theory (Tisdall and Oades, 1982) probably because soil of Gambari Forest Reserve does not contain variable charge clay minerals. Oades (1988) and Kaiser *et al.* (2012) found that soils with 2:1 mineral clay type show increase in organic carbon content with decreasing aggregate sizes pattern and most soils of the tropics with 1:1 mineral clay type do not exhibit this pattern. The amount of organic carbon associated with aggregate of >2.0 mm (macro-aggregates) correspond with its proportion by weight (mass) in bulk soil of Natural Forest and Cultivated Land. Therefore, a large proportion of soil carbon stock may be attributed to aggregate >2.0 mm in Natural Forest and Cultivated Land. Despite tillage, Cultivated Land contained more carbon associated with soil aggregates than

Plantation Forest at topsoil, subsoil and deep soil layers. This indicated that tillage has little or no effect on soil carbon at three layers and this confirmed the study of Chacon *et al.* (2015) that cultivated soil may contain higher carbon content than forest soil due to high inputs of organic matter. Tillage method and land management practice on the cultivated land probably maintained and enhanced soil organic matter and such management practice should be encouraged. Blanco-Connqui *et al.* (2004) stated that cultivation practice that reduces the disruption of macro-aggregates will enhance soil organic carbon sequestration. Furthermore, soil aggregates of surface soil contained high carbon concentration in the three land use types and macro-aggregate fraction (>2.0 mm) responsible for carbon accumulation in Natural Forest and Cultivated Land while micro-aggregate (<0.05 mm) was responsible for carbon accumulation in the Plantation Forest. The Plantation Forest was characterized with high fine clay sized aggregates. Similar result was reported by Deng *et al*., (2014) who observed that afforestation on arable land did not lead to immediate increase in soil organic carbon fraction within 30 years but instead lead to redistribution of carbon fraction in the soil profile. Therefore, low soil organic carbon was observed probably because the age of Plantation Forest is below 30 years. High proportion of aggregate <0.05 mm may be responsible for carbon storage capacity of Plantation Forest to retain more soil organic carbon at the surface soil. The adsorptive efficiency of aggregate >2.0 mm to accumulate soil carbon in Cultivated Land was higher than the Natural Forest, since, 42.56% and 41.12% of aggregate >2.0 mm contained 11.29% and 7.41% of carbon at the surface soil of Natural Forest and Cultivated Land, respectively. Also, proportion (31.14%) of aggregate fraction <0.05 mm contained 5.12% of soil carbon at the surface soil of Plantation Forest. Therefore, carbon adsorptive capacity of aggregate <0.05 mm in soil of Plantation Forest was higher than carbon adsorptive capacity of aggregate >2.0 mm in the topsoil of

Natural Forest and Cultivated Land.

Conclusively, soil aggregate >2.0 mm of subsoil and deep soil layers of Cultivated Land had more capacity to store carbon than aggregates of Natural and Plantation Forests. Also, aggregate <0.05 mm of topsoil of Plantation Forest had more capacity to store carbon than aggregates of Natural Forest and Cultivated Land at the topsoil. Carbon concentration of soil aggregate fractions at the topsoil was higher than subsoil and deep soil layers despite carbon storage capacity of individual aggregate increased with increase in depth in the three land use types. However, concentration of soil carbon among aggregate sizes was greater in Natural Forest than Plantation Forest and Cultivated Land. Changes in capacity of aggregates and concentration of carbon along soil depth show that surface soil is more susceptible to land use change. Hence, change in carbon concentration at the surface soils are important for carbon accumulation but may not be necessary for stabilization and sequestration. However, high total carbon at the surface soil and subsurface soil in Natural forest may be explained by high litter decomposition and fine root biomass production, respectively.

Aggregates of Cultivated Land have lower carbon content than Natural Forest in the plough layer because it had been under cultivation for at least 5 years. Large values of carbon among aggregates of Cultivated land may be due in part to the short period of agricultural tillage (period of conversion from natural to farm land is about 5 years). According to Zhao *et al.* (2006), reduced physical disturbance from tillage would minimize carbon loss from aggregate fractions.

The macro-aggregates have high carbon adsorption capacity and therefore, represent a significant carbon reservoir in soil of Natural Forest and Cultivated Land. High carbon concentration occurred in >1.0 aggregates, followed by <2.0 mm in Natural Forest. However, high carbon concentration occurred in >2.0 mm aggregates, followed by <0.05 mm in Cultivated Land and Plantation Forest. Therefore, land management practices did not lead to carbon loses but redistribution of carbon in soil profile.

Conclusion and Recommendation

Plantation Forest contained large carbon reservoir in the top 45 cm depth, followed by Natural Forest and Cultivated Land. Therefore, Plantation Forest is a good carbon sequestration option in Gamabri forest Reserve. The aggregate distribution of Plantation Forest and Cultivated land is independent of land management types. Large proportion of aggregate size >2 mm indicates low potential for soil carbon protection in soil of Natural Forest and Cultivated Land while large proportion of aggregate <0.05 mm indicate high potential for soil adsorption and protection in soil of Plantation Forest. Total carbon content of soil fractions decreased with increase in soil depth. Therefore, depth and land use types lead to redistribution of carbon in mineral soil of Gambari Forest Reserve.

Deep soil layer should be considered for carbon sequestration in Natural Forest and Plantation Forest while topsoil should be considered for carbon sequestration in Cultivated Land of Gambari Forest Reserve.

References

Akinyemi, D. O. (1998). *Ecological studies of dry lowland rainforest: case study of Onigambari Forest Reserve*. A dissertation submitted to the Department of Forest Resources Management, University of Ibadan, Ibadan, Nigeria. 47pp

Alvarez, C. R., Taboada, M. A., Perelman, S. and Morras, H. J. M. (2014). *Topsoil structure in no-tilled soils in the Rolling Pampa, Argentina. Soil Research* 52: 533-542

Bajracharya, R. M., Lal, R. and Kimble, J. M. (1998). *Long –term tillage effect on soil organic carbon distribution in aggregates and primary particle fractions of the two Ohio soils*. In: Lal, R., Kimble, J. M., Folletti, R. F. and Stewart, B. A. (eds.), Management of Carbon Sequestration in Soil. CRC Press, Boca Raton, Florida, USA. Pp353-367

Bakare, J. (1989). *Assessment of crop performance in A Taungya Age Series in Gambari Forest Reserve*. Unpublished M. Sc. thesis in the Department of Forest Resources Management. University of Ibadan. 85p

Baldock, J. and Skjemstad, J. (2000). Role of the soil matrix and minerals in protecting natural organic material against biological attack. *Organic Geochemistry* 31: 697-710

Blanco-Conqui, H. and Lal, R. (2004). *Mechanisms of carbon sequestration in soil aggregates*. Critical Reviews in Plant Science. 23(6): 481-504

Brogowski, Z. and Kwasowski, W. (2012). Distribution of organic matter in the particle size fractions of Lateritic soil (Plinthosol). *Soil Science Annual* 63 (4): 9-12

Chacon, P., Lorenz, K., Lal, R., Calhoun, F. G. and Fausey, N. R. (2015). Association of soil organic carbon with physically separated soil fractions in different land uses of Costa Rica. *Acta Agriculturae Scandinavica, Section B - Soil and Plant Science* 65(5): 448-459. Doi: 10.1080/09064710.2015.1020859

Deng, L., Liu, G. B., Shanggan, Z. P. (2014). Land use conversion and changing soil carbon stocks in China's Grain-for-Green' Program: a synthesis. *Global Change Biology* 20: 3544-3556

Dhillon. G. S. and Van Rees, K. C. J.

(2017). Soil organic carbon sequestration by shelterbelt agroforestry systems in Saskachewan. *Canadian Journal of Soil Science* 97 (3): 394-409

Fang, X., Chen, F., Wan, S., Yang, Q. and Shi, J. (2015). Topsoil and deep soil organic carbon concentration and stability vary with aggregate size and vegetation types in Subtropical China. *PLOS ONE* 10 (9): 1-17

Feng, W., Plante, A. F. and Six, J. (2013). Improving estimate of maximal organic carbon stabilization by fine soil particle. *Biogeochemistry* 112. 81-93. Doi. 10.1007/s10533-011-9679-7

Franzluebbers, A. J. (2002). Soil organic matter stratification ratio as an indication of soil quality. *Soil and Tillage Research* 66: 95-106

Herold, N., Schoning, I., Michalzik, B., Trumbore, S. and Schrumpf, M. (2014). Controls on soil carbon storage and turnover in German landscapes. *Biogeochemistry* 119(1-3): 1-17. Doi. 10.1007/s10533-014-9978-x

Kaiser, M., Ellerbrock, R. H., Wulf, M., Dultz, S., Hierath, C. and Sommer, M. (2012). The influence of mineral characteristics on organic matter content, composition and stability of topsoils under long-term arable and forest land use. *Journal of Geophysical Research* 117: G02018. Doi. 10.1029/2011JG001712

Mackay, (1923). *Geological map of Nigeria*. Federal Department of Soil Survey.150 pp

Mcgregor, (1934). Nigeria soil survey. *Oxford Forestry Memoir.*18: 1-10

Oades, J. M. (1988). The retention of organic matter in soils. *Biogeochemistry* 5(1): 35-70

Ostrowska, A., Porebska, G. and Kanafa, M. (2010). Carbon accumulation and distribution in profiles of forest soils. *Polish Journal of Environmental Studies* 19 (6): 1307-1315

Park, E. and Smucker, A. J. M. (2005). Dynamics of carbon sequestered in concentric layers of soil macroaggregates. *Korean Journal of Ecology* 28 (4): 181-188

Rowell, D. L. (1994). Soil *Science: Methods and Applications*. First Edition. Addison Wesley Longman Limited, Edinburg Gate, UK. 350pp

Rumpel, C. and Kogel-Knabner, I. (2011). Deep soil organic matter – a key but poorly understood component of terrestrial carbon cycle. *Plant Soil* 338: 143-158

Sausen, L. S., Schaefer, G. F. P., Tomazi, M., Santos, L.S., Bayer, C. and Rosa, L. M. G. (2014). Clay content drives carbon stocks in soils under a plantation of

Eucalyptus saligna Labill. in Southern Brazil. *Acta Brasilica* 28 (2): 266-273

Schumacher, B. A. (2002). *Methods for the determination of total organic carbon in soils and sediments*. Ecological Risk Assessment Support Center, United State Environmental Protection Agency (USPA). 22pp

Soil and Plant Analysis Council (SPAC) (1999). *Analysis handbook of reference methods*. First edition, CRC Press LLC, Florida, USA. 178pp

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 American Journal* 64: 681-689

Sollin, P., Homann, P. and Caldwell, B. A. (1996). Stabilization and destabilization of soil organic matter: mechanisms and controls. *Geoderma* 74: 65-105

Tisdall, J. M. and Oades, J. M. (1982). Organic matter and water stable aggregates in soils. *Journal of Soil Science* 33: 141-163

Wambsganss, J., Stutz, K. P. and Lang, F. (2017). European beech deadwood can increase soil organic carbon sequestration in forest topsoils. *Forest Ecology and Management* 405: 200-209

Zhao, L., Sun, Y., Zhang, X,, Yang, X. and Drury, C. F. (2006). Soil organic carbon in clay and silt sized particles in Chinese mollisols: Relationship to the predicted capacity. *Geoderma* 132: 315-323

Zhang, W. J. and Liu, C. H. (2012). Some thoughts on global climate change. *Environmental Skeptic and Critics* 1(1): 1-7