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Effect of land-use on particulate organic carbon and carbohydrates distributions in dry- and wet-sieved stable aggregates in an ultisol

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ABSTRACT

Particulate organic carbon (POC) and carbohydrates (R-CHO) distributions in dry- and wet-sieved aggregates in four land-use types in southern Nigeria were studied. The land-use types were: secondary forest, 5-year fallow plots, cocoa plantation, and 5-year continuous cultivation. The results showed that, land types affected soil organic carbon fractions, soil organic carbon density, bulk density, and aggregate stability. Soil aggregation following 5-year continuous cropping increased the soil bulk density. POC and R-CHO in 4.75-2.0 mm dry-sieved aggregates in forested and 5-year fallow soils were 12.7 and 5.3 g kg⁻¹, respectively. This is compared to 8.9 and 4.1 g kg⁻¹ in cocoa plantation and 8.0 and 4.9 g kg⁻¹, respectively, in 5-year cropping. There was a significant positive correlation between R-CHO and Ksat ($r = 0.811$), and non-significant correlation between R-CHO and MWD. ($r = 0.573$). A positive correlation was also established between POC and MWD ($r = 0.764$). The results also indicated that POC, rather than R-CHO, was more responsible for maintaining the macro-aggregate stability in forested and 5-year fallow soils. Wetting of the soil aggregates in water results in significant losses of POC and R-CHO in 5-year continuous cropping.

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1.0 Introduction

Sequestration of atmospheric CO₂ into soil and soil organic carbon pool dictates acquisition of research information on the amount of soil organic carbon pool under different land use and soil management practices. World soils are important reservoirs of active carbon pool and play a major role in the global carbon cycle as a source or sink for atmospheric CO₂ (Lal, 2004). Soil organic carbon (SOC) represents the largest terrestrial organic C pool and globally contains over 142 Pg carbons (Zhang *et al.*, 2006; Lal, 2004). Therefore, understanding the effect of land-use and management on liable organic fractions could benefit agricultural soil carbon management and climate change mitigation. Studies showed that SOC fractions are characterized by their differential stabilities and densities and have been extensively used as sensitive indicators to the conse-

quences of land use changes and management practices (Zhang *et al.*, 2012).

The particulate fraction of soil organic matter acts as a cementing agent to stabilize macro-aggregates and intra-aggregate protection of SOM (Six *et al.*, 2002). More recently, authors have viewed carbohydrates as an aggregate binding agent because of the stability it confers to soil aggregates (Liu *et al.*, 2010; Zhang *et al.*, 2012). Particulate organic carbon (POC) and carbohydrates (R-CHO) are important to soil organic matter (SOM) turnover and respond much faster to land use and soil management changes than the total SOM and passive fractions (Sequeira *et al.*, 2011).

Six *et al.* (2002) proposed physical fragmentation of bulk SOC pool into four fractions according to their different protection mechanisms. These fractions are the unprotect-

ed inter-aggregate and intra micro-aggregate SOC, physically protected SOC, mineral associated SOC, and chemically and biochemically protected SOC. The POC and R-CHO fall within the intra micro-aggregate and physically protected fractions of SOC (Courtier-Murias *et al.*, 2013). Particulate organic carbon (POC) and R-CHO storage in dry- and wet-sieved aggregates would give a diagnostic link and/or an opportunity to understand the effect of different land use and management practices on SOC biodegradation (Six *et al.*, 2002). In addition, POC and R-CHO in water-stable aggregates of soils are important components that stabilize organic C and thus drive carbon sequestration under different land use and management (Cambardella *et al.*, 2001; Zhang *et al.*, 2012). POC and R-CHO make up about 25 to 72% of bulk SOM most affected by land use, although literature on their long-term effects in physical protection of soil aggregates is still not well understood (Hu *et al.*, 1995; Piccolo, 2001).

The estimation of POC and R-CHO storage in stable aggregates has been based on few data, especially in the Tropics. Many reviews have been published on the subject, but each of these authors had decried the lack of good data on POC and R-CHO distribution in dry- and wet-sieved aggregates with changing land use (Spaccini *et al.*, 2004; Li *et al.*, 2011; Li *et al.*, 2016; Guo *et al.*, 2018). In southern Nigeria, Mbagwu and Piccolo (1998) observed that carbohydrates and SOC decreased with decreasing wet-sieved aggregate diameter. Whereas, in the cool plateau region of central Nigeria, Adamu *et al.* (1997), under similar soil types, found that smaller dry aggregates were preferentially enriched in carbohydrates relative to macro aggregates. Zeller and Dambrine (2011) found more carbohydrates in the clay- and silt-sized fractions (< 50 µm). Gosling *et al.* (2013) observed that organic matter additions and inclusion of fallows were the primary factors controlling POC and carbohydrates content of agricultural soils.

These inconsistencies show that there are gaps in knowledge on the influence of land use on POC and carbohydrates storage in wet- and dry-sieved aggregates, especially in some tropical soils (Udom and Ogunwale, 2015). Thus, the aim of this study was to evaluate particulate organic carbon and carbohydrates in wet- and dry-sieved aggregates under land-use types in humid tropical ultisols. This will advance our knowledge in bridging the gap on the potential alteration of POC and R-CHO during aggregate disruption by slaking in water under cultivated and uncultivated landscape.

2. 0 Materials and methods

2.1. The study area and soil sampling

The study was carried out on a 385-ha sandy loam soil in Ikwuano local government area in Abia State, southeastern agro-ecological zone of Nigeria (Latitude 5°20' and 5° 30' N, and Longitude 7° 28' and 7° 42' E). The study was conducted in 2018; the slope of the area is 5%, with elevation ranging between 109 m and 152 m above sea level. The rainfall regime is characterized by erosive tropical rainfall that may cause severe erosion problems on hill slope soils. Mean annual rainfall is between 1,800 mm and 2,500 mm, with two peaks in the months of July and October. Mean annual maximum temperature is 31°C, with mean monthly minimum and maximum of 20° C and 34° C, respectively (Spaccini *et al.*, 2001). We selected four land use types within the same soil in this study. They are:

(1) a dense secondary forest soils covering about 100 ha (Forested), (2) 5-year fallow land covering about 100 ha, dominated mainly by shrubs such as *Alchornea cordifolia* and *Ficus exasperata* which are usually harvested during fallow as fuel woods and staking sticks for yams (5-year fallow), (3) Cocoa plantation soils, extending about 120 ha, (cocoa plantation) and (4) 5-year continuous cultivated soils extending 85 ha, under continuous cassava cultivation (5-year cropping). Each land use area was divided into 5 transects (blocks), based on variations in the physiographic position of the landscape. In each transect, five (5) replicate disturbed composite bulk and core soil samples each were collected. A total of 100 bulk and 100 soil core samples were collected at 0-30 cm depth, labeled for ease of identification and transferred to the laboratory for analysis.

2.2. Laboratory analyses

2.2.1. Particle size distribution, pH and bulk density

Particle size distribution was analyzed by the modified hydrometer method (Gee and Or, 2002). Soil pH was determined in soil/distilled water ratio of 1:2.5 using the Bechman's zeromatic pH meter (Thomas, 1996). Bulk density was determined with the core samples by the method described by Blake and Hartge (1986) as:

$$\text{Bulk density} = \frac{\text{mass of oven-dried soil (g)}}{\text{volume of bulk soil (cm}^3\text{)}} \quad (1)$$

2.2.2. Saturated hydraulic conductivity, aggregate stability and organic carbon density

Saturated hydraulic conductivity (K_{sat}) was measured in the laboratory by the constant head soil core method (Reynolds *et al.*, 2002). The final leachate flow rate was determined from the equation:

$$K_{\text{sat}} = \frac{Q}{AT} \times \frac{L}{\Delta H} \quad (2)$$

where K_{sat} is saturated hydraulic conductivity (cm h^{-1}), Q is volume of water (cm^3) that flows through a cross-sectional area of the core A (cm^2), T is time (s), L is length of core (cm), and ΔH is hydraulic head difference (cm). Permeability class was according to Soil Survey Staff (1993). Aggregate stability was measured by the mean wet diameter (MWD) of water stable aggregates from the equation (Hillel, 2004):

$$\text{MWD} = \sum_{i=1}^n X_i W_i \quad (3)$$

where X_i is the mean diameter of any particular size range of aggregates separated by sieving and W_i is the weight of aggregates in that size range as a fraction of the total dry weight of the sample analyzed. Total organic carbon (TOC) was determined by the wet combustion method (Nelson and Sommers, 1996). Soil organic carbon density for 0-30 cm depth expressed as soil carbon stock of the area was calculated as:

$$\text{SOC} = C \times Db \times D \quad (4)$$

where SOC is soil organic carbon density (kg m^{-2}), C is soil organic carbon content (g kg^{-1}), Db is soil bulk density (g cm^{-3}), and D is the soil depth (m).

2.2.3. Fractionation of wet-and dry-sieved aggregates used for the determinations of particulate organic carbon and carbohydrates

Water-stable aggregates were measured by wet-sieving procedure as described by Nimmo and Perkins (2002), using 4.75 mm natural aggregates placed in the top most of sieves of different sizes 2.0, 1.0, 0.5, and 0.25 mm, pre-soaked in distilled water for 10 min before oscillated vertically in water 20 times in a mechanical agitator. The stable aggregates remaining on each sieve were oven-dried at 50° C for 24 h and weighed. Dry-sieved aggregates, 4.75–2.0, 1.0–0.5, 0.5–0.25 and < 0.25 mm size-fractions were obtained by dry sieving through a nest of sieves used in wet-sieving. The wet- and dry-sieved aggregates obtained were stored and used for the determinations of POC and carbohydrates.

Particulate organic carbon in the stable aggregates was determined using the method described by Pereira de Souza et al. (2016). In this method, 5 g of each aggregate were dispersed in 15 ml of 5 g l⁻¹ sodium hexametaphosphate by shaking for 15 h in a reciprocal shaker. The dispersed samples were quantitatively transferred to conical flasks and the POC determined by wet oxidation method. The acid-hydrolyzable carbohydrates were determined using the phenol-sulphuric acid procedure of Safarik and Santruckova (1992) and Piccolo et al. (1996) after hydrolysis of the sample at room temperature for 16 h.

2.5. Data analysis

Data analysis was done using the SAS software (SAS, 2016). Parametric statistics of ANOVA was carried out to test significant differences between land use and management at $p < 0.05$. Means were separated using Fisher's protected test (LSD) (Gomez and Gomez, 1984) at 5% probability. Correlation analysis was carried out between particulate organic carbon and carbohydrates with other soil properties. Significant correlation coefficient was tested at 5% probability.

3. Results and Discussion

3.1. Particle-size distribution, pH and bulk density

Effects of land-use on particle-size distribution, pH, and bulk density are shown in Table 1. Particle-size distribution is dominated by the sand fraction; reflecting the weathered sandstone parent material. The soil is sandy clay loam to sandy loam at 0-30 cm topsoil. 5-year cropping has the highest sand content of 709 g kg⁻¹, suggesting tendency of loss of fine-soil particle fractions during continuous cropping (Table 1). Clay content ranged from 109 g kg⁻¹ in 5-year cropping to 276 g kg⁻¹ in soils under Cocoa plantation. The dominance of sand fraction in particle size distribution is typical of most tropical soils developed on coastal plain sands and sandstone (Akamigbo, 1984). This usually have implication on low water holding capacity of the soil, especially in continuous cropping (Senjobi and Ogunkunle, 2010).

Soil pH ranged between 5.2 in 5-year cropping to 6.2 in forested soil. Although the values were not significantly different ($p > 0.050$, among the land uses, the value of 5.2 found in 5-year cropping soil tends to indicate loss of basic cations due to continuous cropping earlier reported by Igwe *et al.* (2006). The soils under 5-year fallow and Forested showed significant decrease in bulk density in comparison to the 5-year cropping and Cocoa plantation soils. However, the overall mean bulk density across the land use types were within acceptable threshold values for seedling emergence and root penetration of most arable crops (Udom and Ehilegbu, 2018). Also, the significant reduction in bulk density exhibited in Forested and 5-year fallow soils in Table 1 indicated structural improvement due to the significant contribution of high SOC content of the soil in Table 2. Krol *et al.* (2013) and Udom and Ehilegbu (2018) reported that decomposition process of plant residues usually promote soil faunal activities which consequently encouraged build-up and stabilization of soil structure and improved soil granulation. Higher bulk density value in 5-year cropping was evidence of disruption of soil aggregates in the 5-year cropping due to cultivation. This result is consistent with Udom and Ehilegbu (2018) who had reported increasing sand content with high bulk density following continuous cropping.

Table 1: Soil texture, pH, and bulk density of the soils under the different land uses at 0-30 cm

Land use	Sand (g kg ⁻¹)	Silt (g kg ⁻¹)	Clay (g kg ⁻¹)	Texture	pH	BD (Mg m ⁻³)
Forested	542c	197a	261a	SCL	6.2a	1.34b
5-year Fallow	699b	115b	186b	SCL	5.5a	1.34b
Cocoa plantation	593c	131b	276a	SCL	5.8a	1.49a
5-year Cropping	709a	182a	109c	SL	5.2a	1.51a

Means followed by the same letter in each column for each parameter were not significantly different at $p < 0.05$. BD – bulk density, SCL – sandy clay loam, SL – sandy loam

Table 2

Saturated hydraulic conductivity, aggregate stability and soil organic carbon density at 0-30 cm

Land use	Ksat (cm h ⁻¹)	MWD (mm)	SOC (g kg ⁻¹)	SOCD (kg m ⁻²)	Permeability class*
Forested	32.5a	1.69a	21.3a	8.56a	Rapid
5-year Fallow	21.3b	1.25b	16.5b	6.63b	Moderately slow
Cocoa plantation	8.2c	0.81c	10.5c	4.69c	Very slow
5-year Cropping	6.1c	0.76c	8.3c	3.76c	Very slow

Means followed by the same letter in each column for each parameter were not significantly different at $p < 0.05$. Ksat- saturated hydraulic conductivity, MWD – mean weight diameter, SOC – total organic carbon, SOCD- soil organic carbon density

3.2. Hydraulic conductivity, aggregate stability and soil organic carbon density

The effect of land use and management on saturated hydraulic conductivity (K_{sat}) was significant ($p < 0.05$). The highest K_{sat} value of 32.5 cm h^{-1} was found in Forested soil in comparison to very low K_{sat} value of 6.1 cm h^{-1} found in 5-year cropping soils (Table 2). K_{sat} values ranked in the order of Forested > 5-year fallow > Cocoa plantation > 5-year cropping. Aggregate stability (MWD) was significantly affected by the land uses (Table 2), with the highest value of 1.69 mm found in Forested soils, in comparison to the lowest value of 0.76 mm obtained in 5-year cropping.

The trend in MWD and K_{sat} agreed with the assertion that MWD usually promote saturated hydraulic conductivity of soils (Udom and Ogunwale, 2015; Nwite, 2015). It also exhibited the significant effect of land use on soil organic carbon (SOC) and soil organic carbon density (SOCD) within the 0-30 cm soil depth. The highest SOC and SOCD of 26.3 g kg^{-1} and 8.56 kg m^{-2} , respectively, were obtained in Forested soils. Soil organic carbon density was in the order of Forested > 5-year fallow > cocoa plantation > 5-year cropping depicting greater effect of forest and fallow system on the quantity of soil organic matter deposit. Generally, the results further showed that conversion of forest land to arable cropping in 5 years depleted total SOC by 61% and soil organic carbon density within 0-30 cm depth by 56.1%, whereas, 5-year fallow returned about 2.54 kg m^{-2} of SOC to the soil (Table 2).

Further, the high saturated hydraulic conductivity (K_{sat}) in Forested and 5-year fallow soils could be associated with the development of macro pores following interacting effects of soil biological activities on soil aggregation in fallowed soils (Shaoshan et al., 2010; Six and Paustian, 2014;). The very low K_{sat} found in 5-year cropping soil was not surprising because, continuous cultivation reduced K_{sat} through surface and subsurface sealing by clay-size particles, increasing soil compaction and reduction in effective pore spaces, consistent with reports of Šimanský (2011); Kadlec et al. (2012) and Šimanský (2013).

3.3. Particulate organic carbon in dry and wet sieved aggregates

Particulate organic carbon (POC) in dry- and wet-sieved aggregate fractions reflected the influence of land use and management (Figure 1). In both the dry- and wet-sieved aggregates, POC was significantly higher ($p < 0.05$), in macro aggregate > 0.25 mm in Forested and 5-year fallow soils compared with the 5-year cropping. The highest POC value of 12.7 g kg^{-1} was stored in 4.75-2.0 aggregates size class in the dry- and wet-sieved samples in Forested soils, followed with 11.0 g kg^{-1} found in the 2.0-1.0 mm macro-aggregates. Lower POC was consistent in 5-year cropping for both dry- and wet-sieved aggregates, showing the negative effect of continuous cropping and wetting on the labile soil organic carbon fraction.

On the whole, 37.6 g kg^{-1} representing about 81% of the POC was found in the overall macro aggregates (> 0.25 mm). Whereas, 36.8, 37.3, and 15.3 g kg^{-1} representing 97%, 93%, and 60% of POC was stored in macro aggregates (> 0.25 mm) in soils under 5-year fallow, Cocoa plantation and 5-year cropping respectively, (Fig 1). Macro aggregates were preferentially enriched in POC, indicating significant protection of POC in dry-sieved macro aggregates. Consequently, wet-sieving decreased POC in macro and micro aggregates. For example, wet-sieving decreased POC in

macro aggregates > 0.25 mm by 15.4, 42.4 and 64.6% in Forested, 5-year fallow and Cocoa plantation soils respectively. The POC was preferentially stored in dry- and wet-sieved macro aggregates, especially in Forested and 5-year fallow soils compared with Cocoa and 5-year cropping, reflecting the amount of SOC densities in the 0-30 cm soil.

Although the POC in aggregate size classes rarely followed consistent gradient with increasing SOC content, land use had certain effects on POC contents in soils (Stelzer et al., 2014). It is believed that changes in size distribution of soil aggregates following land use changes had little effects on the POC content, which led to the conclusion that either environment (climate) had a more significant role or only a small fraction of soil organic carbon was involved (Shoashan et al., 2010; Li et al., 2010). It is also likely that changes and distribution in stable aggregates was driven by the labile organic bonding compounds which consist mainly of the transient and temporary organic binding agents (Ashagrie et al., 2007).

3.4. Carbohydrates in dry and wet sieved aggregates

Carbohydrates (R-CHO) occluded in various aggregate fractions in dry- and wet-sieved aggregates showed significant differences ($P < 0.05$) (Fig.2). The R-CHO content in 4.75-2.0 mm aggregates ranged between 2.9 g kg^{-1} and 5.3 g kg^{-1} in dry-sieved and 3.5 g kg^{-1} and 2.2 g kg^{-1} in wet-sieved aggregates, suggesting significant loss of R-CHO during wetting and slaking in water. In both dry- and wet-sieved aggregates, R-CHO was significantly higher in macro aggregates in the other of Forested>5-year fallow >Cocoa plantation soils. However, 5-cropping created a shift in R-CHO accumulation to micro aggregates (< 0.25 mm). Comparing the R-CHO in dry- and wet-sieved aggregates to test its resistance to wetting and slaking, there was indication that wet-sieving caused depletion of R-CHO following loss of soil organic matter. In Fig. 2, carbohydrate (R-CHO) was preferentially stored in 4.75-2.0 mm dry-sieved aggregates and in micro aggregates < 0.25 mm in wet-sieved soils.

This result further confirmed that carbohydrate is susceptible to wetting and slaking, and can be used to evaluate the effects of tropical rains on macro- and micro-aggregate stability of forested and cultivated soils (Shoashan et al., 2010; Li et al., 2011; Udom and Ogunwale 2015; Li et al., 2016). It is possible that wetting caused degradation and loss of carbohydrates because, carbohydrates make up a significant part of labile pool of SOM which is usually more sensitive to land use and has been considered along with humic substances as models for the labile and stable fractions of SOC pool (Guggenberger et al. 1995; Spaccini et al., 2000).

The POC and R-CHO as intra-aggregate and physically protected fraction of SOC have implications on the overall soil surface state and maintenance of macro-aggregate stability within 0-30 cm soils under Forested and 5-year fallow. Results further confirmed that wetting and slaking of the soil in water created a shift in POC and R-CHO storage to micro-aggregate with possible consequential negative effect on loss of soil materials during continuous cropping of tropical sandy loam soils (Mbagwu and Piccolo, 1998; Udom and Ogunwale, 2015). Five-year fallow rebuilt the soil organic carbon stock, improved water stability of aggregates, and increased protection of POC and R-CHO in macro-aggregates. They can be used to assess the overall improvement and degradation of soil resources.

3.5. Relationship between carbohydrates, particulate organic carbon and soil properties

Relationships showed a significant positive correlation between R-CHO and Ksat ($r = 0.811$, $p < 0.05$), and non-significant correlation with MWD ($r = 0.573$) (Table 3). There was a positive correlation between POC and MWD ($r = 0.764$, $p < 0.05$), showing that R-CHO and POC con-

tributed over 70% to soil water conditions, and aggregate stability of the soils. There was also a positive linear correlation coefficient between TOC and R-CHO ($r = 0.809$, $p < 0.05$) showing that SOM accumulation benefited carbohydrates contents (Li et al., 2016), especially in Forested and 5-year fallow soils.

Figure 1 Particulate organic carbon distributions in dry and wet sieved aggregates under the different land use at 0-30 cm soil. Columns followed by the same letters for each aggregate size class were not significantly different at $p > 0.05$

Figure 2 Carbohydrate distributions in dry and wet sieved aggregates under the different land use at 0-30 cm. Columns followed by the same letters for each aggregate size class were not significantly different at $p > 0.05$

Table 3: Correlation coefficient (R) between carbohydrates, particulate organic carbon and soil properties

Independent	Dependent	R
R-CHO (g kg ⁻¹)	K _{sat} (cm h ⁻¹)	0.811*
R-CHO (g kg ⁻¹)	MWD (mm)	0.573ns
POC (g kg ⁻¹)	K _{sat} (cm h ⁻¹)	0.741*
POC (g kg ⁻¹)	MWD (mm)	0.764*
TOC (g kg ⁻¹)	R-CHO (g kg ⁻¹)	0.809*

*Significant at $p < 0.05$, ns- not significant, R-CHO – carbohydrates, POC – particulate organic carbon, TOC – total organic carbon, K_{sat} – saturated hydraulic conductivity, MWD – mean weight diameter

5. Conclusion

Conclusions drawn from this study are that: uncultivated forest and 5-year fallow increased soil organic carbon density in the 0-30 cm soil. Particulate organic carbon and carbohydrates are sensitive to land use and management and can reduce significantly within 5-year continuous cropping. Forested and 5-year fallowed soils increased macro aggregate formation while 5-year continuous cropping increased micro aggregates. Particulate organic carbon and carbohydrates are more dominant in macro aggregates > 0.25 mm in Forested and 5-year fallowed soils, while 5-year continuous cropping increased the storage of particulate organic carbon and carbohydrates in micro-aggregates < 0.25 mm. Wet-sieving had greater effect on carbohydrate losses than the particulate organic carbon. Particulate organic carbon rather than carbohydrate was more responsible for macro-aggregate stability of forested and 5-year fallow soils. Positive correlations between POC, R-CHO and MWD showed that POC and carbohydrates took part in soil aggregation and consequently induced stable structure. Increasing fallow period to 5 years after conversion of forest for arable crop production improved macro-aggregate formation and protected POC and R-CHO from degradation.

Declaration of interest

The authors declare that they have no conflicts of interest.

References

- Adamu, J., Mbagwu, J. S. C. and Piccolo, A. 1997. Carbon, nitrogen and phosphorus distributions in aggregates of forest and cultivated soils in central plateau, Nigeria. In: Drozd, J., Gonet, S. S., Senesi, N. & Weber, J. (Eds.). *The Role of Humic Substances in the Ecosystem and in Environment Protection. IHSS-Polish Society of Humic Substances*, Wroclaw, Poland. pp 257-261.
- Akamigbo, F. O. R. 1984. The accuracy of field textures in a humid tropical environment. *Soil Surv. Land Eval.* 4: 63–70.
- Ashagrie, Y., Zech, W., Guggenberger, G. and Mamo, T. 2007. Soil aggregation and total particulate organic matter following conversion of native forests to continuous cultivation in Ethiopia. *Soil Till. Res.* 94: 101- 108.
- Blake, G. R. and Hartge, K. H. 1986. Bulk density. In: Klute, A. (Ed). *Methods of Soil Analysis. Part I. Physical and Mineralogical Methods. Agronomy Monograph 9*. 2nd ed. ASA and SSSA. Madison.
- Cambardella, C. A., Gajda, A. M., Doran, J. W., Wienhold, B. J. and Kettler, T.A. 2001. Estimation of particulate and total organic matter by weight loss-on-ignition. In: *Assessment Methods for Soil Carbon* (eds. Lal, R., Kimble, J. M., Follett, R. F. & Stewart, B. A. CRC Press, Boca Raton, FL. pp. 349–359.
- Courtier-Murias, D., Simpson, A. J., Marzadori, C., Baldoni, G., Ciavatta, C., Fernandez, J. M., Lopez-De-Sa, E. G. and Plaza, C. 2013. Unraveling the long-termstabilization mechanisms of organic materials in soils by physical fractionation and NMR spectroscopy. *Agriculture, Ecosyst. Environ.* 171: 9–18.
- Gee, G. W. and Or, D. 2002. Particle Size Distribution. In: Dane, J. H. & Topp, G. C. (Eds.). *Methods of Soil Analysis, Part 4 Physical Methods. Soil Science Society of America Book Series No.5*, ASA and SSSA, Madison, WI. pp. 255-293.
- Gomez, K. A. and Gomez, A. A. 1984. *Statistical Procedures for Agricultural Research*. 2nd ed., Wiley Interscience Publication, Singapore.
- Gosling, P., Parsons, N. and Bending, G.D. 2013. What are the primary factors controlling the light fraction and particulate soil organic matter content of agricultural soils? *Biol., Fert. Soils* 49: 1001–1014.
- Guggenberger, G., Zech, W. and Thomas, R. J. 1995. Lignin and carbohydrate alteration in particle-size separates of an oxisol under tropical pastures following native savanna. *Soil Biol. Biochem.* 27: 1629–1638.
- Guimaraes, D. V., Gonzag, M. I. S., Dasilva, T. O., Dasilva, T. L., Dias, N. S. and Matias, M. I. S. 2013. Soil organic matter pools and carbon fractions in soils under different land uses. *Soil Till. Res.* 126:177-182.
- Guo, Z. C., Zhang, Z. B., Zhou, H., Rahman, M. T., Wang, D. Z., Guo, X. S., Li, L. J. and Peng, X. H. 2018. Long-term animal manure application promoted biological binding agents but no soil aggregation in a vertisol. *Soil Till. Res.* 180: 232-237.
- Hillel, D. 2004. *Introduction to Environmental Soil Physics*. Elsevier Academic Press, Austerdar. pp 494.
- Hu, S., Coleman, D. C. Scare, M. H. and Hendrix, P. F. 1995. Soil carbohydrates in aggrading and degrading agroecosystems: influences of fungi and aggregates. *Agriculture, Ecosyst. Environ.* 54: 77-88.
- Igwe, C. A., Zarei, M. and Stahr, K. 2006. Clay dispersion of hard setting Inceptisols in Southern Nigeria as

- influenced by soil components. *Communications in Soil Sci. Plant Analysis* 37: 751-760.
- Kadlec, V., Holubík, O., Procházková, E., Urbanová, J. and Tippl, M. 2012. Soil Organic Carbon Dynamics and its Influence on the Soil Erodibility Factor. *Soil Water Res.* 7: 97-108.
- Krol, A., Lipiec, J., Turski, M. and Kus, J. 2013. Effects of organic and conventional management on physical properties of soil aggregates. *International Agrophysics* 27: 15-21.
- Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. *Science* 304: 1623-1627.
- Li, Y. F., Jiang, P. K., Chang, S. X., Wu, J. S. and Lin, L. 2010. Organic mulch and fertilization affect soil carbon pools and forms under intensively managed bamboo (*Phyllostachys praecox*) forests in south-east China. *J. Soils Sediments* 10: 739-747.
- Li, J. J., Zhao, X. and Pan, T. H. 2011. Influence of land use on soil labile organic carbon. *J. Soil Water Conser.* 25: 147-151.
- Li, S., Gu, X., Zhuang, J., An, T., Pei, J., Xie, H., Li, H., Fu, S. and Wang, J. 2016. Distribution and storage of organic carbon of soil with low fertility. *Soil Till. Res.* 155: 199-206.
- Liu, H., Tong, X. G., Xu, Y. M., Ma, X. W., Wang, X. H., Zhang, W. J. and Xu, M. G., 2010. Evolution characteristics of organic carbon fractions in gray desert soil under long-term fertilization. *Plant Nutr., Fert. Sci.* 16: 794-800.
- Mbagwu, J. S. C. and Piccolo, A. 1998. Water-dispersible clay in aggregates of forest and cultivated soils in southern Nigeria in relation to organic matter constituents. In: Bergstrom, L. & Kirchman, H. (Eds.) Carbon and Nutrient Dynamics in Natural and Agricultural Ecosystems. CAB International, UK. pp. 71-83.
- Nelson, D. W. and Sommers, L. C. 1996. Total carbon, organic carbon and organic matter. In: Sparks, D. L. (Ed.). Methods of Soil Analysis, Part 3, Chemical Methods. *Soil Science Society of America*, Madison, WI, USA, pp. 539-579.
- Nimmo, J. R. and Perkins, K. S. 2002. Aggregate stability and size distribution. In Dane, J. H. & Topp, G. C. (Eds.) Methods of Soil Analysis. Part 4. Physical Methods. *Soil Science Society of America*, Madison, WI, USA, pp. 317-328.
- Nwite, J. N. 2015. Assessment of soil structural stability under different landuses using some predictive indices in Abakaliki, Southeastern Nig. *Curri. Agric. Res.* 3: 1-3.
- Pereira de Souza, G., Celia de Figueireda, C. and Gomes de Sousa, D. M. 2016. Relationships between labile carbon fractions under different soil management systems. *Scientia Agricola* 73: 2015-2047.
- Piccolo, A. 2001. The Supramolecular structure of humic substances. *Soil Sci.* 166: 810-832.
- Piccolo, A., Zena, A. & Conte, P. 1996. A comparison of acid hydrolysis for the determination of carbohydrates in soils. *Comm. Soil Sci. Plant Analysis* 27: 2909-2915.
- Reynolds, W. D., Elick, D. E., Youngs, E. G., Amoozegar, A. and Bootink, N. W. 2002. Saturated and Field-saturated Water Flow Parameters, In: Dane, J. H. & Topp, G. C. (Eds.). Methods of Soil Analysis, Part 4. *Soil Science Society of America*, Madison, WI, USA, pp. 797-878.
- Safarik, I. and Santruckova, H. 1992. Direct determination of total soil carbohydrate content. *Plant and Soil* 143: 109-114.
- SAS-Statistical Analysis System. 2016. Institute SAS/STAT User's Guide, 4th ed., Vol. 1. SAS Inst. Cary, NC, USA.
- Senjobi, B. A. and Ogunkunle, O. A. 2010. Effect of Land Use on Soil Degradation and Soil Productivity Decline on Alfisols and Ultisols in Ogun State in Southern Western Nigeria. *Journal of Agriculture & Conspectus Science*, Faculty of Agriculture, University of Zagreb, Croatia 75: 9-19.
- Sequeira, C. H., Alley, M. M. and Jones, B. P. 2011. Evaluation of potentially labile soil organic carbon and nitrogen fractionation procedures. *Soil Biol. Biochem.* 43: 438-444.
- Shaoshan, A., Axel, M., Herwing, M. and Winfried, E. H. 2010. Soil aggregation, aggregate stability, organic carbon and nitrogen in different soil aggregate fractions under forest and shrub vegetation on the Loess Plateau, China. *Catena* 81: 226-233.
- Šimanský, V. 2011. Soil structure of Haplic Luvisol as influenced by tillage and crop residues ploughing. *Acta phytotechnica et zootechnica* 14: 27-29.
- Šimanský, V. 2013. Soil organic matter in water-stable aggregates under different soil management practices in a productive vineyard. *Archives Agron. Soil Sci.* 59: 1207-1214.
- Six, J. and Paustian, K. 2014. Aggregate-associated soil organic matter as an ecosystem property and a measurement tool. *Soil Biol. Biochem.* 68: 44-49.
- Six, J., Callewaert, P., Lenders, S., De Gryze, S., Morris, S., Gregorich, E., Paul, E. and Paustian, K. 2002. Measuring and understanding carbon storage in afforested soils by physical fractionation. *Soil Sci. Soc. Amer. J.* 66: 1981-1987.
- Soil Survey Staff. 1993. Soil Survey Manual. USDA, Soil Conservation Service, Agricultural Handbook No. 18, Print Office, Washington, DC, USA.
- Spaccini, R., Piccolo, A., Haberhauer, G. and Gerzabek, M. H. 2000. Transformation of organic matter from maize residues into labile and humic fractions of three European soils as revealed by ¹³C distribution and CP/MAS-NMR spectra. *European J. Soil Sci.* 51: 583-594.
- Spaccini, R., Zena, A., Igwe, C. A., Mbagwu, J. S. C. and Piccolo, A. 2001. Carbohydrates in water-stable aggregates and particle size fractions in forested and cultivated soils in two contrasting tropical ecosystems. *Biogeochem.* 53: 1-22.
- Spaccini, R., Mbagwu, J. S. C., Igwe, C. A., Conte, P. and Piccolo, A. 2004. Carbohydrates and aggregation in

- lowland soils in Nigeria as influence by organic inputs. *Soil Till. Res.* 75: 161–172
- Stelzer, R. S., Scott, J. T., Bartsch, L. A. and Parr, T. B. 2014. Particulate organic matter quality influences nitrate retention and denitrification in stream sediments: evidence from a carbon burial experiment. *Biogeochem.* 119, 387–402.
- Thomas, G. W. 1996. Soil pH and soil acidity. In: Methods of soil analysis, *Part 3*, Chemical Methods. *Soil Science Society of American Book Series* No.5 ASA and SSSA, Madison, WI. pp. 475-490.
- Tisdall, J. M. and Oades, J. M. 1982. Organic matter and water-stable aggregates in soils. *J. Soil Sci.* 33, 141–163.
- Udom, B. E. and Ehilegbu, J. 2018. Critical moisture content, bulk density relationships and compaction of cultivated and uncultivated soils in the humid tropics. *Asian Soil Res. J.* 1: 1-9.
- Udom, B. E. and Ogunwole, J. O. 2015. Soil Organic Carbon, Nitrogen, And Phosphorus Distribution In Stable Aggregates Of An Ultisol Under Contrasting Land Use And Management History. *J. Plant Nutr. Soil Sci.* 178: 460–467.
- Zhang, X., Chen, L., Fu, B., Li, Q., Qi, X. and Ma, Y. 2006. Soil organic carbon changes as influenced by agricultural land use and management: a case study in Yanhuai Basin, Beijing, China. *Acta Ecologica Sinica* 26: 3198-3204.
- Zhang, S. X., Li, Q., Zhang, X.P., Wei, K., Chen, L.J. and Liang, W.J. 2012. Effects of conservation tillage on soil aggregation and aggregate binding agents in black soil of Northeast China. *Soil Till. Res.* 124: 196–202.
- Zeller, B. and Dambrine, E. 2011. Coarse particulate organic matter is the primary source of mineral N in the top-soil of three beech forests. *Soil Biol. Biochem.* 43: 542–550