

RESEARCH ARTICLE

(Open Access)

Aggregate-associated carbon in a cultivated soil under short-term planted cover crop

SHADE AKINSETE*

Department of Soil Science and Land Management, College of Plant Science and Crop Production, Federal Univ. of Agriculture, Abeokuta. P.M.B. 2240, Abeokuta, Ogun State, Nigeria.

Abstract:

Cultivation and agronomic practices (cropping density) influences soil carbon (C) and changes the distribution and stability of soil aggregates. Aggregation and aggregate-associated C content were studied in three depths of a cultivated soil planted with *Mucuna jaspidea* at three plant densities (25, 50, and 75%) in southwestern Nigeria. Dry and water stable aggregates were separated into six classes (< 0.25, 0.25 – 0.5, 0.5 – 1, 1 – 2, 2 – 4, and > 4 mm). The largest proportions of dry and water-stable aggregates (WSA) in the soil surface (0 – 15 cm) depth were in the order: 0.25 – 0.5 mm > 0.5 – 1 mm > microaggregate (< 0.25 mm) size classes, but the smallest proportion (9%) of dry aggregate distribution was found in the 2 – 4 mm size class. Cultivation resulted in reduction of the proportion of large (> 4 mm) dry and water-stable macroaggregates. Consequently, there was a shift in size distribution of aggregates > 4 mm to the 1 – 2 mm aggregate size. Among the plant densities, the largest concentrations of C were found in the 0.25 – 2 mm dry macroaggregates isolated from 0 – 15 and 15 – 30 cm depths, while the largest C concentration was within the 0.5 – 1 mm WSA. The results show cultivation enhanced the disruption of aggregates and redistribution of C which predisposes the loss of C. It was also indicated that macroaggregates were sensitive to cultivation especially at the soil surface, thus, could be an indicator in evaluating the impacts of soil management.

Keywords: Aggregate, soil organic carbon, microaggregate, macroaggregate, cover crop

1. Introduction

Soil aggregation and organic carbon (OC) are important properties of the soil that play complementary roles. Soil aggregation influences organic carbon storage, at the same time OC is a major agent in improving and stabilizing soil aggregates. Cultivation affects aggregation, as well as OC accumulation in soil. Cultivation not only destroys soil aggregation, which results in the loss of SOC [5; 1] but also changes the distribution and stability of aggregates [4].

Soil aggregate class is broadly divided into macro- (> 0.25 mm) and micro-aggregates (< 0.25 mm). Macro-aggregates are very sensitive to land use changes, largely stabilized by labile OC fraction, formed from stable microaggregates but less stable than microaggregates, whereas, microaggregates are less sensitive to land use changes, stabilized by more recalcitrant OC, and more stable than macroaggregates [14; 11; 8]. Previous studies [11; 8; 16] have indicated the varying distribution and storage of C in different aggregate classes. While some studies reported the higher OC contents in macroaggregates [11], others have reported higher levels of OC in microaggregates [10]. In addition to

soil C storage, soil aggregates are of critical importance to soil productivity, structure maintenance, greenhouse gas emission and soil erosion [9; 6].

Leguminous cover crops have been widely used to improve soil physiochemical properties, such as OC content, nitrogen (N) levels, aggregation, reducing soil loss through erosion, improving water retention and nutrient status of the soil and suppression of weeds. *Mucuna* is a leguminous cover crop used in this study to replace natural fallow. Generally, *Mucuna* is widely used for some beneficial reasons earlier stated for cover crops, and much more used to suppress weed growth in organic farming where the use of chemicals is prohibited. The majority of studies have shown the benefits of cover crop and increasing the plant density has been shown to impact positively on the soil. However, there is little research focusing on aggregation and SOC storage as affected by this cover crop (*Mucuna jaspidea*) in the soil of this study, an important panacea for GHG's emission. Consequently, the objectives of this study were to determine: (i) aggregate-size distribution and, (ii) aggregate-associated C in a soil planted with a cover crop (*Mucuna jaspidea*) at different plant densities.

Correspondence: Shade Akinsete, Department of Soil Science and Land Management, College of Plant Science and Crop Production, Federal Univ. of Agriculture, Abeokuta, PMB 2240, Abeokuta, Ogun State, Nigeria; Email: sjohnadisa@yahoo.com
(Accepted for publication 12 June 2013)

2. Material and Methods

2.1 Site description

The study was conducted at a field located at the Federal University of Agriculture, Abeokuta, Ogun State, Nigeria (latitude - $7^{\circ}12'0''$ N and longitude - $3^{\circ}23'0''$ E). The site was previously a fallow of mixed shrubs, weeds and grasses but was planted with *Mucuna jaspidea* at three plant densities [25% (1 x 0.25 m), 50% (1 x 0.5 m), and 75% (1 x 0.75 m)] for this study in September, 2011. The site is situated in the derived savanna of Nigeria with a bimodal rainfall distribution pattern. The annual rainfall is about 1000 – 1500 mm with two distinct seasons; the wet season (March to October) and the short dry season (November to February). Mean temperature ranges from 21.9°C (minimum) to 29.8°C (maximum). The experimental area (40 m x 19 m) was laid out in a randomized complete block design with three replicates and divided into plot sizes of 3 m x 3 m. The tillage treatments were: (i) plough and harrow, and (ii) slash (no-till) but without replicates, was set aside as control for determining aggregate-size distribution. The particle size distribution was performed by hydrometer method, and the texture was loamy sand at the soil surface depth (0 – 15 cm). Soil pH ranged between 5.0 - 5.4 for the three soil depths.

2.2 Soil sampling

Soil samples were collected from three depths (0 – 15; 15 – 30; 30 – 45 cm) in two mini-pits (60 cm x 60 cm) dug per plot in November, 2011 (12 weeks after planting). Two or more soil cores (7.5 cm diameter x 20 cm deep) were taken from each depth, and samples from the same treatment were pooled together and composite samples taken and air-dried. Undisturbed soil samples were taken for all aggregate determination. The air-dried samples were then passed through a sieve (< 2 mm diameter), and any visible plant materials were manually removed from the sieved soil. Finely ground soil samples were used for carbon analysis.

2.3 Soil organic carbon determination

Soil organic carbon (SOC) for soil samples was determined by wet oxidation method using the chromic-acid procedure [15].

2.4 Dry aggregates separation

The dry aggregates separation was performed using a modified method outlined by [16]. Briefly, 100 g of undisturbed air dried soil cores were placed

on a nest of sieves with 4, 2, 1 and 0.25 mm diameter openings. The set of stacked sieves was thoroughly shaken manually for 12 min. After this time aggregate fractions retained on each sieve was collected, thus yielded 6 aggregate size fractions of > 4, 4 - 2, 2 - 1, 1 - 0.5, 0.5 - 0.25, and < 0.25 mm. Each aggregate fraction was calculated as percentage of the total soil used.

2.5 Wet aggregates separation

Wet aggregates separation was carried out by a modified method outlined by [4]. Briefly, 100 g of undisturbed sample of air dried soil were spread on the top of a nest sieves with 4, 2, 1 and 0.25 mm openings. The samples were left immersed in the water for 10 min and then sieved by moving the sieve 3 cm vertically 50 times during a period of 2.0 min. The mass resultant aggregates on each sieve were dried at 105°C for 24 h and weighed. The percent water stable aggregate (WSA) was derived from the following formula:

$$\% \text{WSA} = \frac{(M_{a+s} - M_s)}{(M_t - M_s)} \times 100$$

Where M_{a+s} is the mass of the resistant aggregates plus sand (g), M_s is the mass of the sand fraction alone (g), and M_t is the total mass of sieved soil (g).

2.6 Statistical analysis

Analysis of variance were performed using SPSS (15.0) package for Windows (SPSS Inc., Chicago, IL, USA). Treatments were considered different at $P = 0.05$ using Duncan's multiple range test.

3. Results and Discussion

3.1 Aggregate-size distribution

The largest proportions of dry aggregates in the soil surface (0 – 15 cm) depth were in the 0.25 – 0.5 mm, followed by the 0.5 – 1 mm size classes and the microaggregate (< 0.25 mm) size class (Fig. 2). The smallest proportion (9%) of dry aggregate distribution was found in the 2 – 4 mm macroaggregate size class (Fig. 2). The largest aggregate size distribution occurred in the plots with 50 and 25 % plant densities, accounting for 27 and 22 % respectively (Fig. 2a). Contrary to the surface soil, aggregate distribution in the sub-surface (15 – 30 and 30 – 45 cm) soil depths revealed a different pattern, in which the largest proportion occurred in the > 4 mm aggregate size class followed by aggregates in the 0.25 – 0.5 mm class of the 25 and 75 % plant densities. The lowest proportion of aggregate distribution at the subsurface depths was constituted the 1 – 2 mm size class.

The distribution of the water-stable aggregate (WSA) followed a similar pattern to that revealed by the dry aggregate size distribution (Fig. 3). Aggregates in the 0.25 – 0.5 mm size class constituted the largest portion, followed by the 0.5 – 1 mm and < 0.25 mm classes. These results agree with [2], who observed a significantly larger proportion of soil was retained as microaggregates and small macroaggregates (0.25 – 0.5 mm) in a cultivated soil. The largest aggregate fraction peaked in the 50% plant

density (27%). In the same way, the distribution of WSA in the subsurface (15 – 30 and 30 – 45 cm) soil depths showed the largest fractions were in the > 4 mm class, followed by those in the 0.25 – 0.5 mm size class. The smallest proportions were consistently in the 1 – 2 and < 0.25 mm size classes. Changes in dry aggregate-size distribution demonstrated a decline in soil aggregation occurs upon short-term cultivation as revealed in this study.

Table 1. Carbon concentration (g kg⁻¹) in dry aggregates under different plant densities

Soil Depth (m)	Plant Density (%)	Aggregate-size class (mm)			
		1 – 2	0.5 – 1	0.25 – 0.5	< 0.25
0 - 15	25	4.32 aA	5.06 aA	5.19 bA	10.73 abB
	50	7.65 bA	7.58 bA	7.78 cA	9.33 aB
	75	4.32 aA	4.92 aA	3.86 aA	12.40 bB
15 - 30	25	2.92 aA	3.93 aA	3.46 aA	3.87 aA
	50	7.85 bB	7.72 cB	6.86 bB	3.20 aA
	75	4.19 aA	5.59 bA	7.31 bB	4.87 aA
30 - 45	25	3.65 aA	4.59 aB	3.45 aA	3.40 aA
	50	3.72 aA	4.39 aA	7.85 bB	3.53 aA
	75	4.66 bB	4.59 aB	7.59 bC	2.93 aA

Values followed by different lowercase letters in the same column are significantly different for plant densities at $P=0.05$ using the Duncan's Multiple Range Test (DMRT)

Values followed by different uppercase letters in the same row are significantly different for aggregate classes at $P=0.05$ using the Duncan's Multiple Range Test (DMRT)

Generally, the 0.25 – 0.5 mm aggregate class at the soil surface (0 – 15 cm) and the > 4 mm at the sub-surface (15 – 30 and 30 – 45 cm) depths constituted the largest fraction both of the dry and water stable aggregates in this study. The aggregate size distribution did not show a specific pattern for the plant densities suggesting plant density did not have any significant effect on aggregation in the study. It is important to note that this is a preliminary result from a short-term study. Also, abrupt cessation of the rainfall in the year of the cover crop establishment in this study may provide the explanation for no significant effect of plant density on aggregate size distribution.

The slash (unploughed) plot served as control, where the soil was left undisturbed. Unlike the cultivated plots, the largest proportion of WSA was in the > 4 mm size for the surface (0 – 15 cm) depth but the surface depths (15 – 30 and 30 – 45 cm) exhibited similar pattern to the ploughed plots thus revealing largest fraction of aggregate in the > 4 mm size (Fig.1). Comparing these results with those of the ploughed plots demonstrates cultivation destroyed macroaggregates especially at the soil surface, which agrees with the conclusion that tillage destroys aggregates > 1 mm in the surface depth [7]

There was a shift in size distribution of aggregates from large macroaggregate (> 4 mm) to the 1 – 2 mm aggregate size with cultivation (Figs. 1, 2 and 3), resulting in a decrease of 13 and 29% in the surface and sub-surface soils respectively in the > 4 mm WSA. However, an increase of 29 and 40% occurred in the 1 – 2 mm aggregate size class in the 0 – 15 and 15 – 30 cm depths respectively, when the soil was cultivated. This corroborates other studies [2], which revealed the influence of cultivation on the destruction of aggregates. This also confirms earlier observations that macroaggregates are dynamic in nature and the size distribution of macroaggregates is affected by the change in land use [13; 2]. Therefore, changes in aggregate size distribution can be used as an indicator of structural degradation.

3.2 Soil organic carbon in aggregates

The SOC concentrations in the dry aggregate size class (mm) ranged from 2.92 to 12.40 g kg⁻¹ (Table 1). Among the three plant densities and soil depths, the highest concentrations was significantly ($p = 0.05$) contained in the microaggregate (< 0.25 mm) size class isolated from the surface (0 – 15 cm) soil depth under the 75% plant density (Table 1)

Generally, among the plant densities, the largest concentrations of SOC were found in the 0.25 - 2 mm macroaggregate size class isolated from 0 – 15 and 15 – 30 cm depths under the 50% plant density. [3] also reported the presence the higher C content within 0.25 – 2 mm macroaggregates. However, at the 30 – 45 cm depth the concentration of aggregate-associated C was nearly even across the different plant densities except for the 0.25 to 0.5 mm aggregate size, where the C concentration was significantly higher under the 50 and 75% plant densities. Contrary to the pattern revealed at the soil surface, the subsurface soil depths revealed significantly lower C concentrations associated with the microaggregate size class, suggesting there was no influence (redistribution) on aggregate-associated C by cultivation, as shown for the surface soil. Total C concentrations in the WSA revealed differential pattern and this varied significantly from 2.59 to 9.19 g kg⁻¹ across the treatments (Table 2). The largest C concentration was within the 0.5 – 1 mm size, while the lowest was associated with the 1 – 2 mm size class. [16] also observed greater C concentration in the 0.5 – 1 mm of the water stable macroaggregates in their study. Other studies have also reported higher OC contents in macroaggregates [11]. Generally, significantly higher C concentration was associated with WSA isolated from the soil under 50% plant density at the 0 – 15 and 15 – 30 cm depths. However, this trend was not consistent for the 30 – 45 cm soil depth (Table 2).

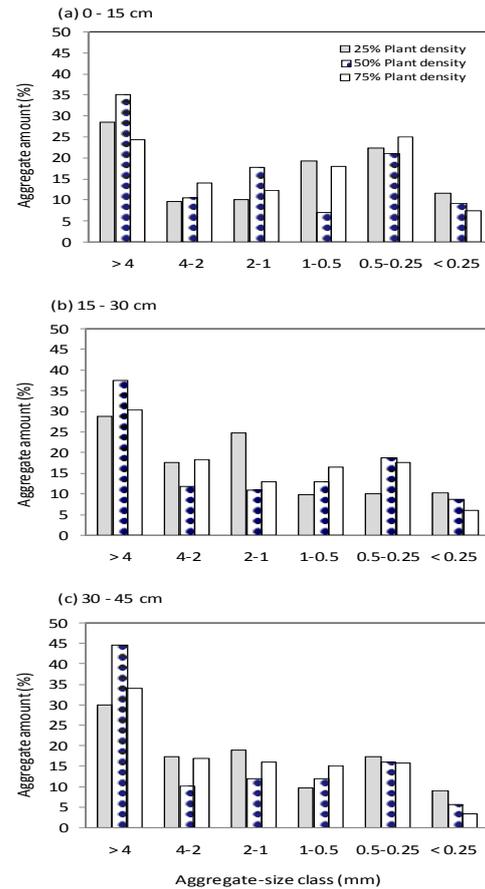


Figure 1. Dry aggregate-size distribution in the slash (no-tillage) treatment under different plant densities isolated from different soil depths: (a) 0 – 15 cm; (b) 15 – 30 cm; and (c) 30 – 45 cm.

Table 2. Carbon concentration (g kg⁻¹) in water stable aggregates under different plant densities

Soil Depth (m)	Plant Density (%)	Aggregate-size class (mm)		
		1 – 2	0.5 – 1	0.25 – 0.5
0 - 15	25	4.88 bA	6.49 aB	4.86 bA
	50	7.78 cA	7.58 bA	7.78 cA
	75	4.04 aA	9.19 cB	3.86 aA
15- 30	25	2.59 aA	4.10 aC	3.19 aB
	50	8.18 cC	4.10 aA	7.79 bB
	75	4.29 bA	5.48 bB	7.65 bC
30 - 45	25	3.78 aA	4.89 bB	3.59 aA
	50	3.60 aA	4.19 aB	8.68 cC
	75	4.99 bA	4.70 bA	7.78 bB

Values followed by different lowercase letters in the same column are significantly different for plant densities at $P=0.05$ using the Duncan's Multiple Range Test (DMRT)

Values followed by different uppercase letters in the same row are significantly different for aggregate classes at $P=0.05$ using the Duncan's Multiple Range Test (DMRT)

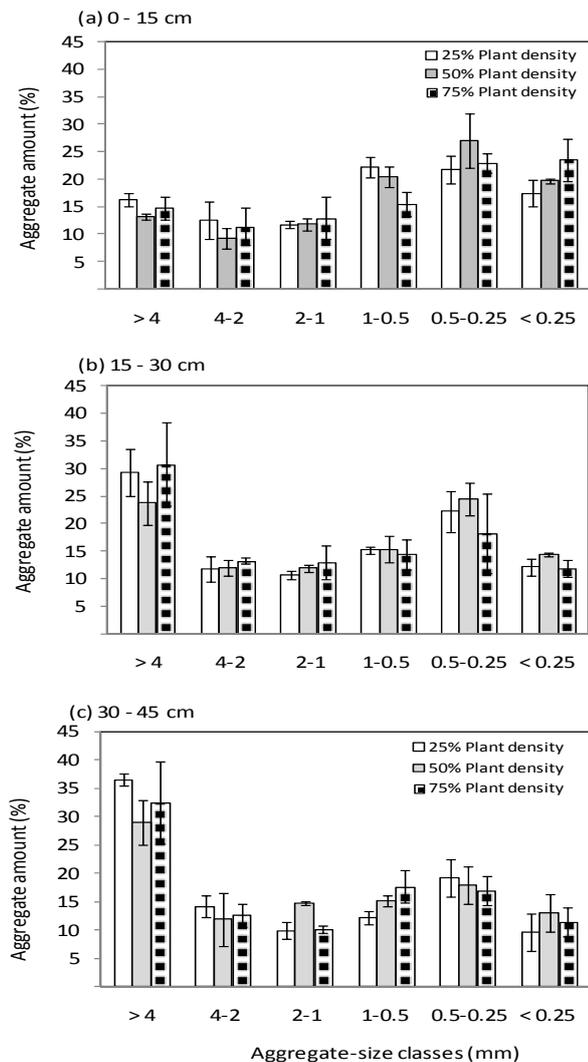


Figure 2. Dry aggregate-size distribution ($n = 3$) in the ploughed treatment under different plant densities isolated from different soil depths: (a) 0 – 15 cm; (b) 15 – 30 cm; and (c) 30 – 45 cm. Bars represent \pm standard error

4. Conclusions

Cultivation resulted in reduction of the proportion of large (> 4 mm) dry and water-stable macroaggregates. Consequently, there was a shift in size distribution of aggregates from large macroaggregate (> 4 mm) to the 1 – 2 mm aggregate size with cultivation. Generally, the largest concentrations of SOC were found in the 0.25 - 2 mm macroaggregate size class isolated from 0 – 15 and 15 – 30 cm depths under the 50% plant density. However, the subsurface soil depths revealed significantly lower C concentrations associated with the microaggregate size class, suggesting there was marked redistribution in aggregate-associated C by

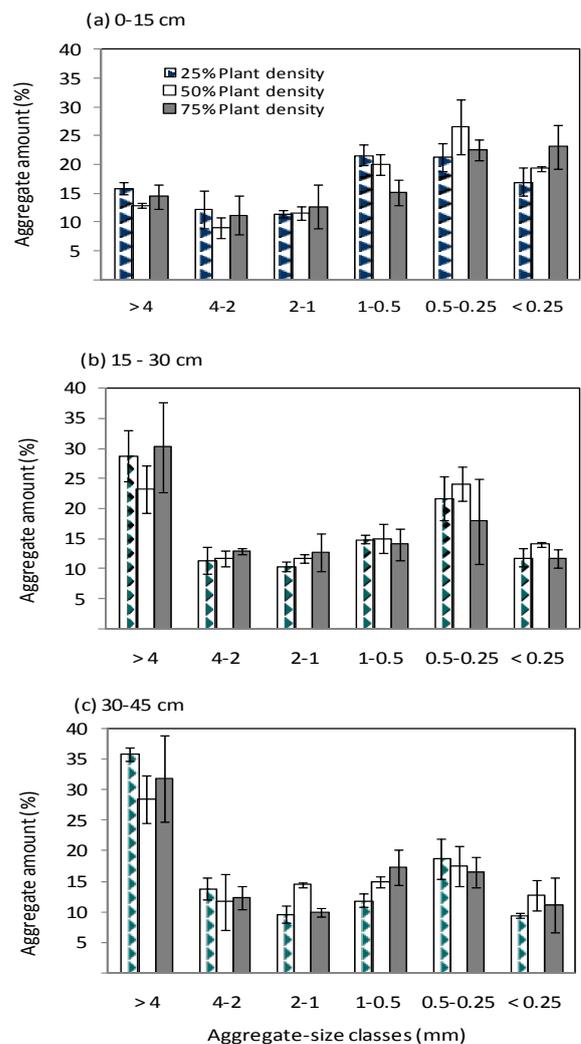


Figure 3. Water-stable aggregate-size distribution ($n = 3$) in the ploughed treatment under different plant densities isolated from different soil depths: (a) 0 – 15 cm; (b) 15 – 30 cm; and (c) 30 – 45 cm. Bars represent \pm standard error

cultivation, as revealed for the surface soil. Generally, plant density did not significantly affect distribution of soil aggregate associated C in this study. In conclusion, cultivation enhanced the disruption of aggregates and redistribution of C which predisposes soil to loss of C.

5. Acknowledgements

I wish to thank Oluwafemi Bashir, Omotola Raji, Stephen Muogho, Sandra Omede and Tokunbo Aina for assistance in processing and analyzing soil samples.

6. References

1. Angers DA, Pesant A, Vigneux J: **Early cropping- induced changes in soil aggregation, organic matter, and microbial biomass.** Soil Science Society of America Journal 1992, 56:115–119.
2. Ashagrie Y, Zech W, Guggenberger G, Mama T: **Soil aggregation, and total and particulate organic matter following conversion of native forests to continuous cultivation in Ethiopia.** Soil Tillage and Research 2007, 94: 101-108.
3. Conant RT, Six J, Paustian K: **Land use effects on soil carbon fractions in the southeastern United States. II. Changes in soil carbon fractions along a forest to pasture chronosequence.** Biology Fertility and Soils 2007, 40: 194-200.
4. Emadi M, Baghernejad M, Memarian HR: **Effect of land-use change on soil fertility characteristics within water-stable aggregates of two cultivated soils in northern Iran.** Land Use Policy 2009, 26:452-457.
5. Elliott ET: **Aggregate structure and carbon, nitrogen, and phosphorus in native and cultivated soils.** Soil Science Society of America Journal 1986, 50: 627–633.
6. Follett RF, Varvel GE, Kimble JM, Vogel KP: **No-till corn after bromegrass: effect on soil carbon and soil aggregates.** Agronomy Journal 2009, 101: 261- 268.
7. John B, Yamashita T, Ludwig B, Flessa H: **Storage of organic carbon in aggregate and density fractions of silty soils under different types of land use.** Geoderma 2005, 128: 63–79
8. Kristiansen SM, Schjønning P, Thomsen IK, Olesen JE, Kristensen K, Christensen BT: **Similarity of differently sized macro-aggregates in arable soils of different texture.** Geoderma 2006, 137: 147–154.
9. Lal R, Follett RF, Stewart BA, Kimble JM: **Soil carbon sequestration to mitigate climate change and advance food security.** Soil Science 2007, 172: 943- 956.
10. Maguire RO, Edwards AC, Wilson MJ, **Influence of cultivation on the distribution of phosphorus in three soils fro NE Scotland and their aggregate size fractions.** Soil Use Management 1998, 14: 147–153.
11. Mikha MM, Rice CW: **Tillage and manure effects on soil and aggregate-associated carbon and nitrogen.** Soil Science Society of America Journal 2004, 68:809–816.
12. Six J, Paustian K, Elliott ET, Combrink C: **Soil structure and organic matter: I distribution of aggregate-size classes and organic matter: I distribution of aggregate-size classes and aggregate-associated carbon.** Soil Science Society of America Journal. 2000, 64:681–689.
13. Spaccini R, Zena A, Igwe CA, Mbagwu JSC, Piccolo A: **Carbohydrates in water-stable aggregates and particle size fraction of forested and cultivated soils in two contrasting tropical ecosystems.** Biogeochemistry 2001, 53: 1- 22
14. Tisdall JM, Oades JM: **Organic matter and water stable aggregates in soil.** Journal of Soil Science 1982, 33: 141–161.
15. Walkley A, Black IA: **An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method.** Soil Science 1934, 37: 29-38.
16. Yang Z, Singh BR, Hansen S: **Aggregate associated carbon, nitrogen and sulfur and their ratios in long-term fertilized soils.** Soil Tillage and Research 2007, 95:161-171.