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Effect of Humic substances on aggregate stability and soil health on different land uses in Ikwuano, Abia State

Simon U.G and O.J Kamalu

Department of Crop and Soil science University of Port Harcourt Choba, Rivers state

ABSTRACT

In highly weathered tropical conditions, soil organic matter is important for soil quality and productivity. Conversion of native forests to cultivation usually causes degradation of soil structure as well as a decline of its nutrients and organic carbon. This study was conducted in Ikwuano, Abia state; the study evaluates effect of humic substances on aggregate stability and soil health in four land-use types. The land-use types include (1) forested, (2) 5 year fallow land, (3) cocoa plantation (4) 5 year land under continuous cassava cultivation. A transect was selected in the individual land-use. In each transect, five (5) stations were sampled at 20m apart. Twenty (20) disturbed and twenty (20) undisturbed soil samples were collected from 0-15 cm and 15-30 cm depths. Findings: land use practices results in major changes in soil organic carbon and organic carbon fractions as well as a major influence on aggregate stability. It further indicated that humic substances are sensitive parameters that reflect differences of soil aggregation which can be used as soil quality indicator. Humified carbon (HC), humic acid carbon (HAC), saturated hydraulic conductivity (Ksat), mean weight diameter(MWD) and water holding capacity (WHC), were positively related at ($p < 0.05$). Fulvic acid carbon (FAC), Ksat and MWD were positively related at ($p < 0.01$). Humified carbon and HAC correlated positively at ($p <0.05$) with MWD, the high positive correlation ($p <0.01$) of FAC with MWD, suggests that FAC played effective role and contributed significantly to aggregate stabilization of the soils than other organic carbon fractions. Land use practices resulted in major changes in organic carbon fractions and aggregate stability.

Key words: Humified carbon, soil health, fulvic acid carbon.

INTRODUCTION

Soil health has been broadly defined as the capacity of a living soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health [1]. Soil organic matter serves as a primary indicator of soil quality and health for both scientists and farmers [2]; [3]. [4] have demonstrated the utility of total soil organic matter and carbon fractions as indicator of soil quality and in assessing the sustainability of conventional and alternative management systems in the US Central Great Plains. Properties related to organic matter content, such as organic carbon fractions (humic acids, fulvic fraction) and aggregate stability can be used as soil quality indicators. They provide early information about mineralization processes, nutrient availability and fertility, as well as effects resulting from changes in land use, or agricultural practices (e.g. tillage or application of different types of organic matter).

Humic substances which are important fractions of soil organic matter (SOM), make up a large portion of the dark matter in humus and as such are high molecular weight compounds that together form the brown to black hydrophilic, molecularly flexible and polyelectrolytes [5]. They play a vital role in soil fertility and plant nutrition. Plants grown on soils which contain adequate humin, humic adds (HAs), and fulvic adds (FAs) are less subject to stress, are healthier, produce higher yields; and the nutritional quality of harvested foods and feeds are superior. The content and quality of humus substances strongly influence the total and labile trace elements content in the soil [6] that can play the role of possible glue agents. They also function to give the soil structure, porosity, water holding capacity, cation and anion exchange, and are involved in the chelation of mineral elements.

In terms of a long term stability of soil aggregates, their humified and hydrophobic components are mainly important in stabilization of aggregates. [7]. Aggregate stability is a reflection of soil structure and soil health in general because it depends on an integrated balance of chemical, physical and biological factors [8]. Organic matter improves soil aggregation or structure formation [9] and mediates many chemical and physical soil properties. Humic substances have significant on soil influence on quality and productivity, as well as a high base exchange capacity, which is important for soil fertility [10].

In the tropics, soil organic matter is an index of the fertility and productivity status of soils, especially when these are highly weathered, with small or no reserves of nutrients, and are managed without any external inputs of organic or inorganic fertilizer [11]. Massive deforestation in the tropics has resulted in loss of soil productivity through reduction in organic C content and consequent loss in aggregate stability [12]. Since the aggregates and particle-size fractions are the seat of organic matter, their loss through rapid decomposition often accompanies deforestation [13]. Moreover, at the global scale the type of land use will affect the capacity of the soil to act as both a source and a sink of organic matter, nutrients and atmospheric CO_2. It is therefore essential that the influence of land use on the dynamics of soil organic matter in the tropics should be more precisely clarified. Thus, the aim of this study is to contribute to the knowledge in the understanding of the effect of humic substances on aggregate stability and soil health on different land uses in Ikwuano, Abia State. Soil organic matter (SOM) enhances the usefulness of soils for agricultural purposes. It supplies essential nutrients and has unexcelled capacity to hold water and absorb cations. It also functions as a source of food for soil microbes and thereby helps enhance and control their activities [14].

MATERIALS AND METHODS

Description of the study area

The study was carried out in Ikwuano, a major food producing area and one of the seventeen local government areas(LGAs) making up Abia State. The study area is bounded in the north by Umuahia LGA, in the south by Ikot-Ekpene, Akwa Ibom State, in the east by Bende LGA and in the west by Isiala Ngwa LGA. The area lies between latitudes 5° 20' and5° 30'' N, longitudes 7° 28' and 7° 42'' E, and it covers an area of about 310 sq.km with elevation ranging from 109 to 152m above mean sea level (Spotlight on Ikwuano Local Government, 1992).

The climatic regime is characterised by erosive tropical rainfall that may cause severe erosion problems to hill slope soils. The average annual rainfall ranges between 1,800 and 2,500 mm / year, with the peak between July and August and the mean annual maximum temperature is 31°C, but mean monthly values vary between 20°C and 34°C (NRCRI, 2003).

Field work and sample collection

A transect was selected in each of the land-use. In each transect, five stations were sampled at 20m apart. A total of forty disturbed and forty undisturbed soil samples were collected from 0-15 cm and 15-30 cm depths and properly labeled for ease of identification and transferred to the laboratory for analysis.

Laboratory analyses.

Soil pH and Particle size analysis

Soil pH was determined in soil distilled water ratio of 1:2.5 by using Bechman's zeromatic pH meter, in a soil:liquid ratio of 1: 2.5 [15].

Particle size distribution was analyzed following the modified hydrometer method (Gee, and Or, 2002), using sodium hexameta-phosphate (calgon) as a dispersant.

Saturated hydraulic conductivity, bulk density and Water holding Capacity

Saturated hydraulic conductivity was measured by the constant head permeameter technique as described by [16] using the equation.

$$\text{Ksat} = \frac{\boldsymbol{Q} \,.\, \boldsymbol{L}}{\boldsymbol{AT} \,.\, \Delta\boldsymbol{H}}$$

Where; Ksat= saturated hydraulic conductivity (cm/hr), Q = volume of water that flows through a cross sectional area (A) cm^2, T = Time elapsed in seconds, L = length of core (cm) and ΔH = Hydraulic head difference (cm).

Bulk density was determined by the method described by Black and [17] as:

$$\text{BD} = \frac{Mass\ of\ oven - dried\ soil\ (g)}{volume\ \ of\ bulk\ soil\ (cm3)}$$

Water holding capacity at saturation (0 kpa) tension after 24hours was calculated using the formula.

$$\text{WHC} = \frac{Mw - Md}{MD}$$

Where W·H·C = water holding capacity, M_d = Mass of oven dried soil and M_w = Mass of wet soil.

Aggregate stability and Organic carbon

Aggregate stability was measured by the Mean Wet Diameter (MWD) method of water stable aggregates as described by Kemper and Rosenau (1986). Water stable aggregates were measured by the Mean weight diameter (MWD) by the following equation [18]

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$$\text{MWD} = \sum_{i-1}^{n} X1\, Wi$$

Where Xi is the mean diameter of any particular size range of aggregates separated by sieving and Wi is the weight of aggregates in that size range as a function of the total dry weight of the sample analyzed. Water-stable aggregate (WSA) was calculated as:

$$\text{WSA} = \frac{MR\ \times 100}{MT\ \times 1}$$

Where, MR is the mass of resistant aggregate (g), and MT is the total mass of wet-sieved soil (g).

Organic carbon was determined by the wet combustion method of Walkley and Black procedure [19].

Humified carbon (HC), Humic acid-carbon (HA) and Fulvic acid carbon (FA)

Humified carbon (HC), Humic acid-carbon (HA) and Fulvic acid carbon (FA) were determined as described by Castagnolic et al (1990).One gram each of the soil samples was weighed into stoppered glass test tubes, 25 ml of a solution of 0.1M NaOH/ 0.1 M pyrophosphate were added into the tubes and then shaken for four hours and thereafter filtered, the organic carbon extracted is termed humified carbon. Ten milliliters of the filtrate was used to determine the organic carbon in the soil as humified carbon by the wet oxidation method of Walkley -Black (1934).For the determination of Humic acid carbon, ten milliliters of the 0.1M NaOH/0.1 M Pyrophoshate extract obtained above were acidified to pH 2 with H_2SO_4. The solution was then heated to 80^oC for 30 minutes in a water bath. After 24 hr, the precipitate was filtered, washed severally with 0.025 M H_2SO_4, the organic carbon in the precipitate is the Humic acid –carbon and was determined by Walkley - Black wet oxidation method.Fulvic acid (FA) was determined as the difference between humified carbon and humic acid.

Data analysis

Data generated was subjected to Analysis of variance (ANOVA) and treatment means were separated using Fisher least significant difference at 5% probability level ($LSD_{0.05}$). Correlation analysis was carried out to find out the way variables relate with each other. All statistical analysis was carried out with the aid of SAS (2001)

RESULTS

Particle size distribution, pH and organic carbon of the soils.

Results of particle size distribution, pH and Organic carbon are presented in Table 1. The particle size distribution ranged from 737.6 – 548.0 g/kg; 215.7 – 123.8 g/kg and 270.8 – 46.7 g/kg for sand, silt and clay fractions respectively for 0-15 cm depth and 759.2 – 536.2 g/kg; 191.4 – 107.2 g/kg and 294.2 – 92.8 g/kg for sand, silt and clay respectively for 15-30 cm depth. The sand fractions varied significantly ($P<0.05$) across the land-use types with the cultivated land having the highest value of 737.6 g/kg and 759.2 g/kg for 0-15 cm and 15-30 cm depths respectively. The lowest value of 548.0 g/kg and 536.2 g/kg for 0-15 cm and 15-30 cm depths respectively was observed in the forested soil. The silt and clay fractions varied significantly ($P<0.05$) across the land-use types with the highest value of 215.7 g/kg and 191.4 g/kg observed in cassava cultivation and forested soils for 0-15 cm and 15-30 cm respectively for silt fractions. The lowest value of silt fractions values 123.8 g/kg was observed in fallow land-use for 0-15 cm and 107.2 g/kg in fallow land for 15-30 cm depths. Clay fractions had highest value 270.8 g/kg and 294.2 g/kg for 0-15 cm and 15-30 cm depths respectively with lowest values of 46.7 g/kg and 92.8 g/kg obtained in cultivated land for 0-15 cm and 15-30 cm depths respectively. pH was moderately acidic in the land-use types at 0-15 cm and 15-30 cm depths. Its values ranged from 6.3 – 5.2 and 6.2 – 5.1 for 0-15 cm and 15-30 cm depth respectively.

Organic carbon (SOC) was significantly different ($P <0.05$) in the land-use types in the 0-15 cm and 15-30 cm depths. Its distribution ranged from 30.2 – 9.2 g/kg and 22.3 – 7.5 g/kg for 0-15 cm and 15-30 cm depth respectively. Organic carbon in Forested soils was highest in both 0-15 cm (30.2 g/kg) and 15-30 cm (22.3 g/kg) depths and lowest in both 0-15 cm (9.2 g/kg) and 15-30 cm (7.5 g/kg) in soils under cassava cultivation. Organic carbon was not significantly different ($P <0.05$) in fallow and cocoa soils for both 0-15 cm and 15-30 cm.

Table 1. Particle size distribution, pH and organic carbon of soils under different land-use

Land use	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	Text. class	pH	TOC (g/kg)
0 -15 cm						
Forested	548.0b	201.8a	250.2a	SCL	6.3a	30.2a
5 year fallow	727.8a	123.8b	148.4b	SL	5.8a	18.5b
Cocoa Plantation	601.6b	127.6b	270.8a	SCL	5.9a	19.8b
5 year cassava cult.	737.6a	215.7a	46.7c	SL	5.2b	9.2c
15 – 30 cm						
Forested	536.2c	191.4a	272.4a	SCL	6.2a	22.3a
5 year fallow	670.8b	107.2b	222.0b	SCL	5.3b	17.0b
Cocoa Plantation	582.4c	123.4b	294.2a	SCL	5.8a	18.2b
5 year cassava cult.	759.2a	148.0a	92.8c	SL	5.1b	7.5c

Means with the same alphabet are not significantly (P <0.05) different. TOC= Total organic carbon, SCL= Sandy clay loam, SL=Sandy loam.

Bulk density, saturated hydraulic conductivity, water holding capacity and mean weight diameter of the soils

Saturated hydraulic conductivity, Bulk density, Water holding capacity and Mean weight diameter of soils under different land-use are presented in Table 2. Bulk density, saturated hydraulic conductivity and water holding capacity varied significantly (P <0.05) across the land-use types. Bulk density was highest (1.49 g/cm) in continuous cultivation for 0-15 cm depths and lowest value of 1.28 g/cm was obtained for forested soils. Continuous cultivation also had the highest bulk density value of 1.51 g/cm at the 15-30 cm and lowest values of 1.34 g/cm were obtained at 15-30 cm depths at forest soils.

Table 2 Saturated hydraulic conductivity, bulk density, water holding capacity and mean weight diameter of soils under different land-use

Land use	Ksat(cm/hr)	BD(g/cm)	WHC(g/g)	MWD
		0 -15 cm		
Forested	9.2c	1.28c	0.44a	1.789a
5 year fallow	16.3b	1.38b	0.34b	1.668b
Cocoa Plantation	7.01c	1.34b	0.47a	1.795a
5 year cassava cult.	35.4a	1.49a	0.32b	1.310c
		15 – 30 cm		
Forested	7.2b	1.34b	0.46a	1.457a
5 year fallow	9.3b	1.40b	0.35b	1.252b
Cocoa Plantation	5.2b	1.38b	0.48a	1.624a
5 year cassava cult.	29.6a	1.51a	0.34b	0.759c

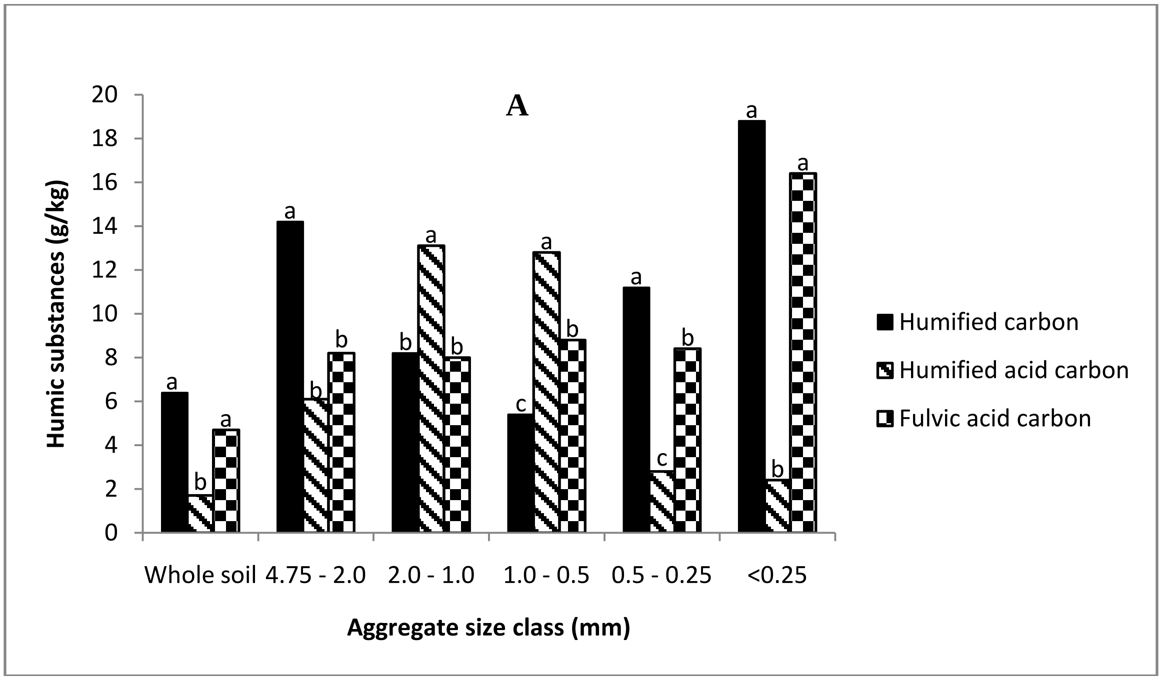
Means with the same alphabet are not significantly (P <0.05) different. Ksat= Saturated hydraulic conductivity, BD= Bulk density, WHC=Water holding capacity, MWD= Mean weight diameter.

Bulk density values were observed to increase with depth in the various land uses. Saturated hydraulic conductivity values was highest (35.4 cm/hr) and 29.6 cm/hr in cultivated soils for 0-15 cm and 15-30 cm depths respectively and varied significantly (P <0.05) to other land-use types. The lowest values of 7.01 cm/hr and 5.2 cm/hr were obtained for cocoa plantation for 0-15 cm and 15-30 cm depths respectively. The WHC of the soils was highest with values of 0.47g/g and 0.48 g/g for 0-15 cm and 15-30 cm depths respectively in the cocoa plantation and lowest in the cultivated land-use with values of 0.32 g/g and 0.36 g/g for 0-15 cm and 15 – 30 cm depths respectively. Mean weight diameter values of 1.789; 1.668; 1.795 and 1.310 were obtained for forested, fallow, cocoa plantation and soils under 5 year continuous cassava cultivation respectively for 0-15cm depths and 1.457; 1.252; 1.624 and 0.759

were obtained for forested, fallow, cocoa plantation and soils under 5 year cassava cultivation respectively for 15-30 cm depths.

Distribution of humic substances in whole and aggregate stability of soils

The influence of land-use on the status of humic substances are presented in Figures 1 - 4.The results show that there was a significant difference (P<0.005) for whole soil and dry and wet-sieved aggregates in the various land-use studied with an exception in 5 year fallow land for whole soils. The highest humified carbon (HC), Humic acid carbon (HAC) and Fulvic acid carbon (FAC) content was obtained in Cocoa plantation with values of 13.5 g/kg; 5.5 g/kg and 11.2 g/kg in whole soils for HC, HAC and FAC respectively.The result followed a decreasing order in land-use management. Thus, Cocoa plantation > 6 year cassava cultivation > Forest land > Fallow land.



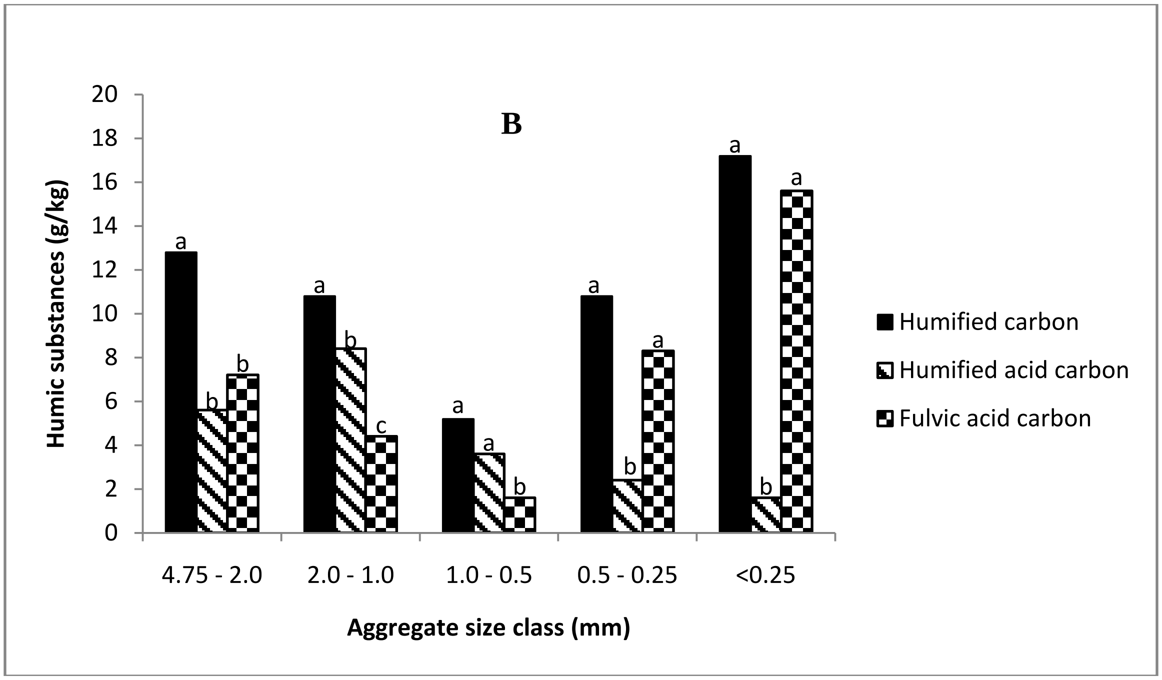
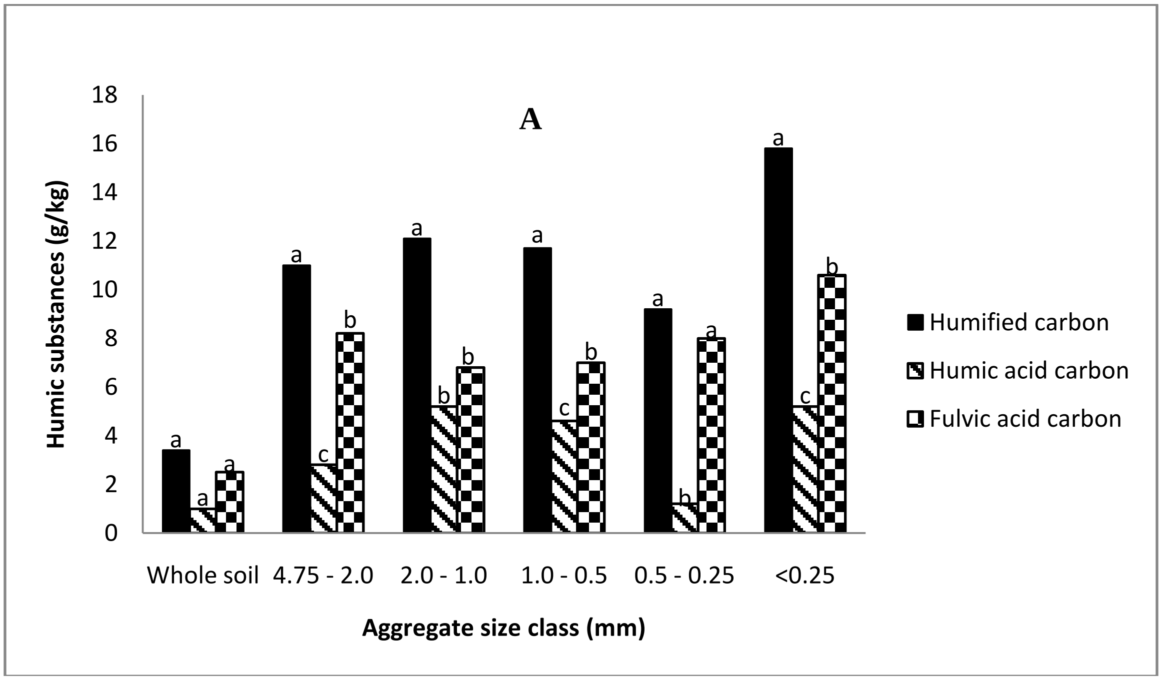


Figure 1. Distribution of humic substances in dry (A) and wet (B) sieved aggregates in Forested soils. Columns followed by the same letters were not significantly different at $p < 0.05$



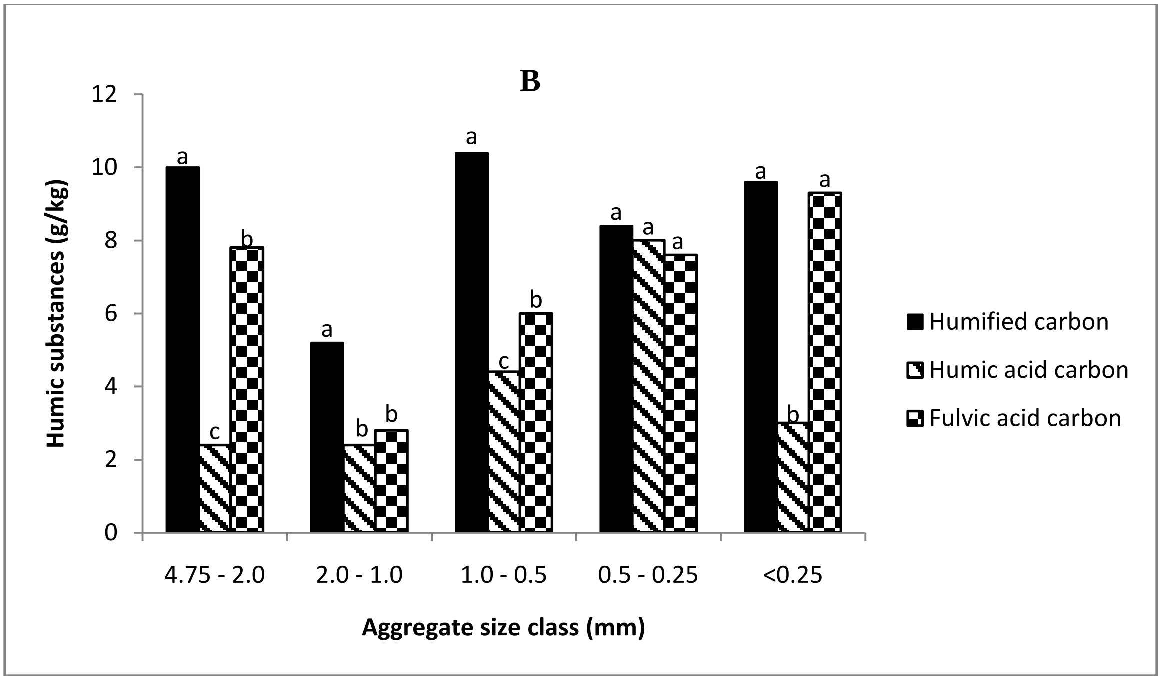
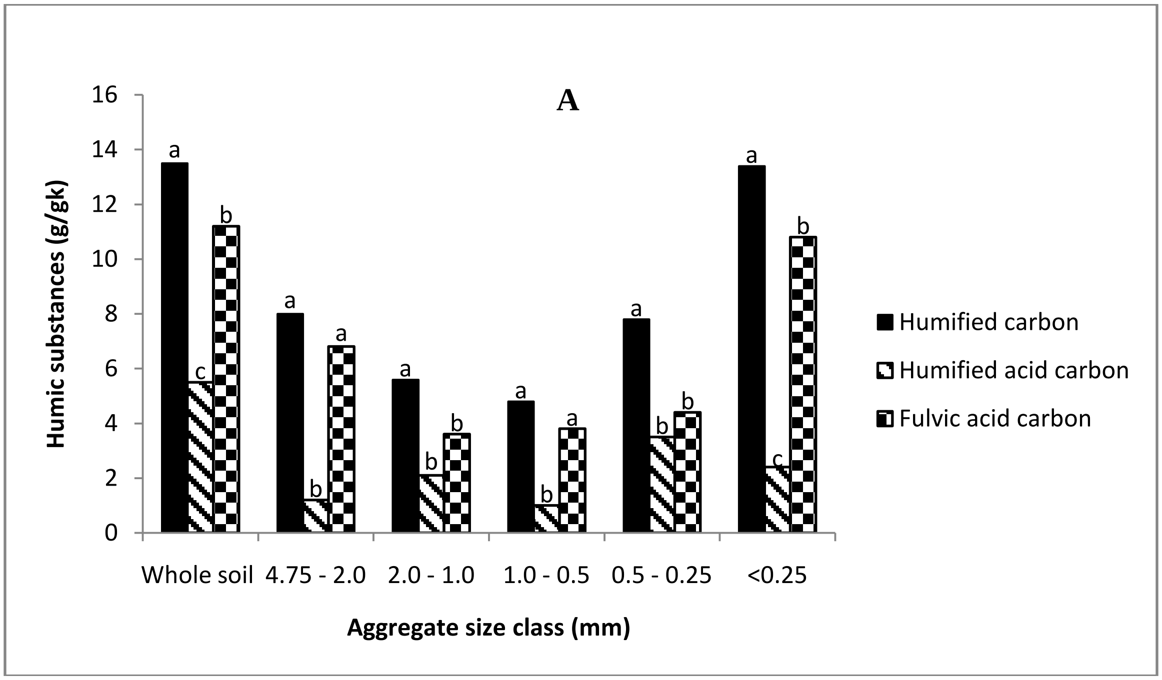


Figure 2. Distribution of humic substances in dry (A) and wet (B) sieved aggregates in 5 year Fallow soils. Columns followed by the same letters were not significantly different at p <0.05



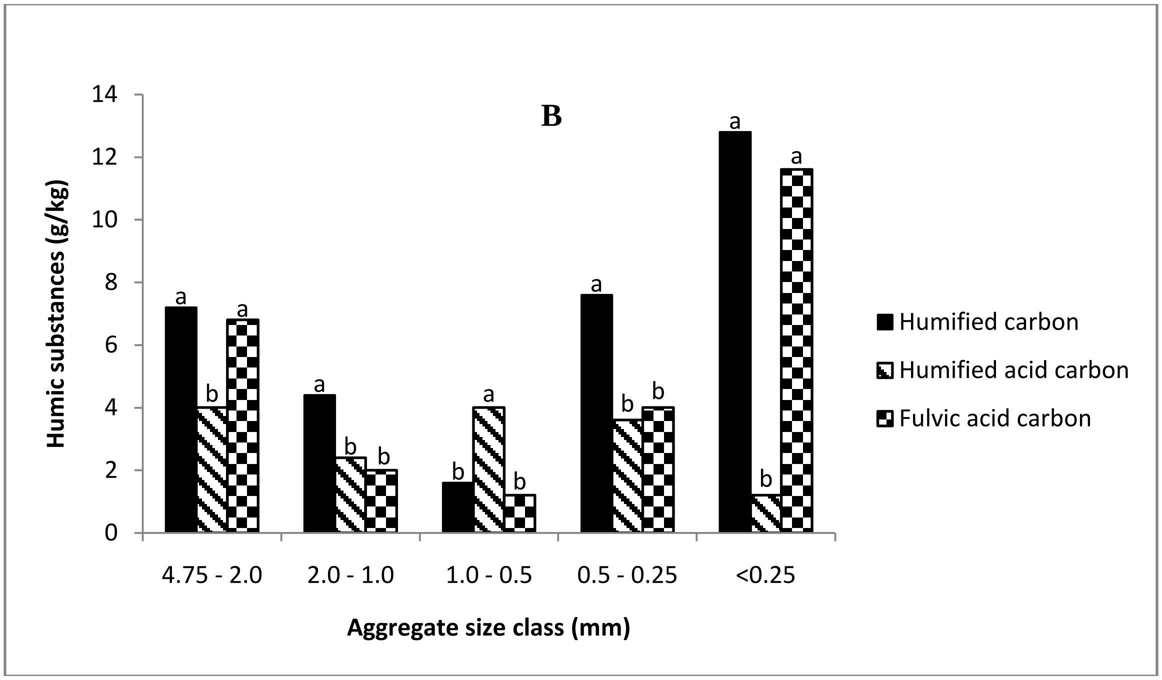
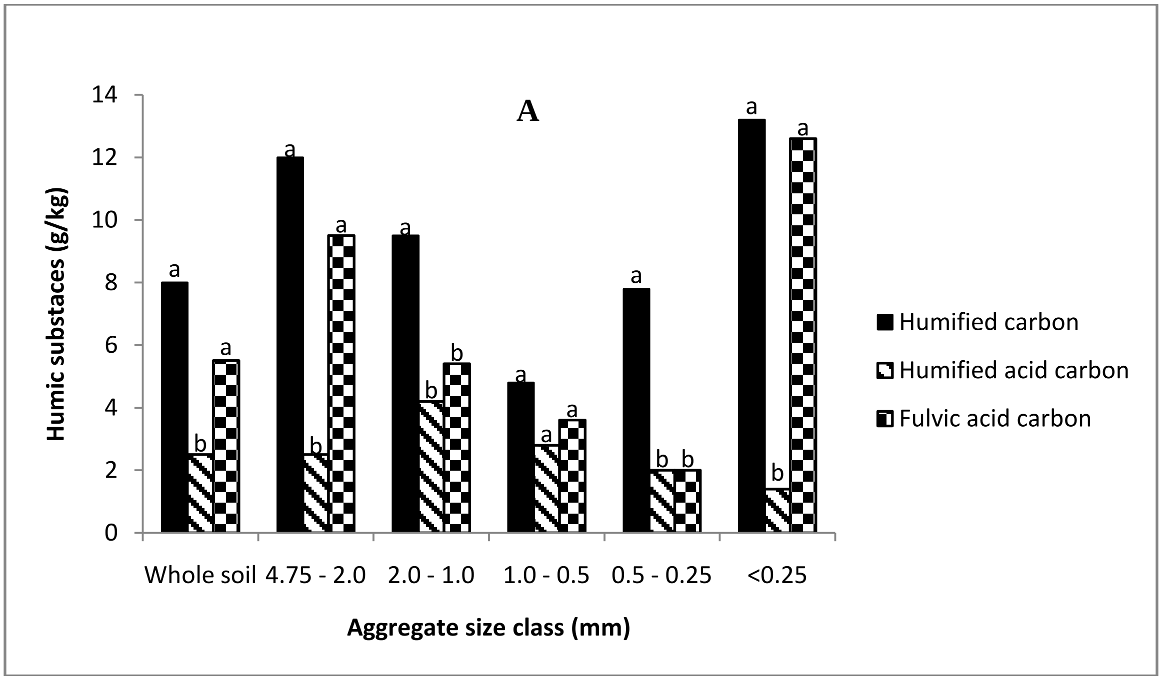


Figure 3. Distribution of humic substances in dry (A) and wet (B) sieved aggregates in cocoa plantation. Columns followed by the same letters were not significantly different at $p < 0.05$



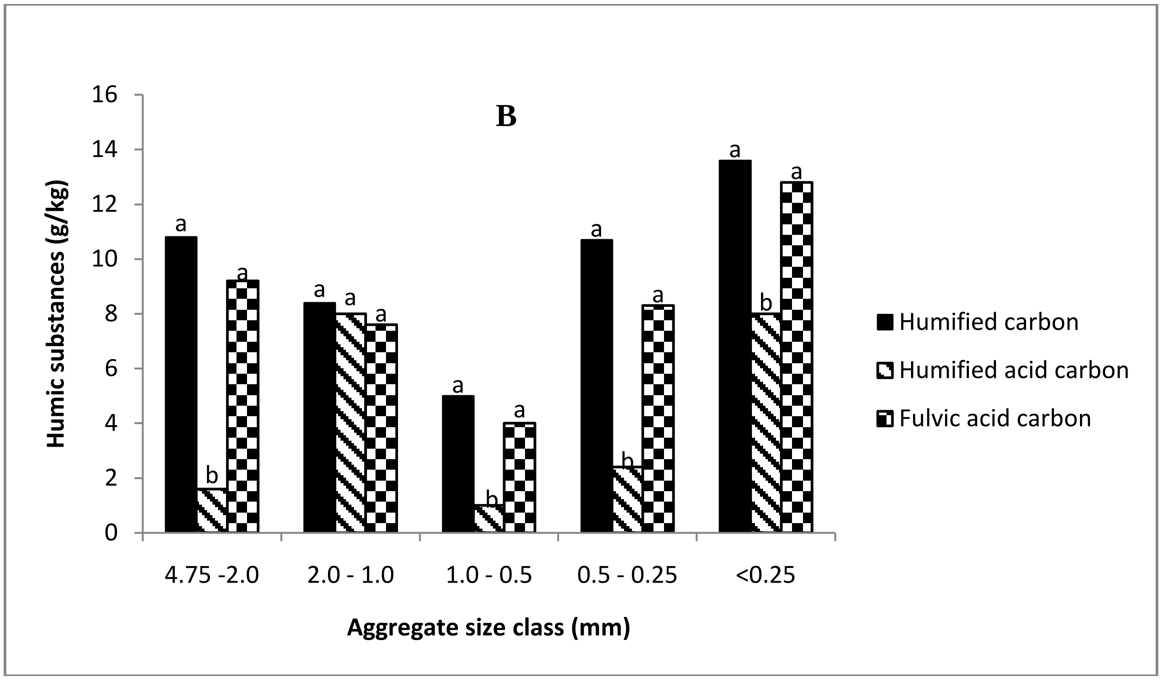


Figure 4. Distribution of humic substances in dry (A) and wet (B) sieve aggregates in 5 year cassava cultivation. Columns followed by the same letters were not significantly different at $p<0.05$

Relationship between Humic substances, carbohydrates, particulate organic carbon and some soil physical properties.

The relationship between Humic substances, carbohydrates, particulate organic carbon and some soil physical properties are shown in Table 3

Humified carbon (HC), Humic acid carbon (HAC) saturated hydraulic conductivity (Ksat), Mean weight diameter (MWD) and water holding capacity (WHC), were positively related at ($p < 0.05$). Fulvic acid carbon, saturated hydraulic conductivity (Ksat) and Mean weight diameter (MWD) were positively related at ($p < 0.01$). Carbohydrates (R-CHO) and saturated hydraulic conductivity were also observed to be positively related at ($p < 0.05$), but had a high positive correlation ($p <0.01$) with mean weight diameter and water holding capacity. Particulate organic carbon (POC), saturated hydraulic conductivity, mean weight diameter and water holding capacity were positively related at ($p <0.05$).

Table 3. Correlation coefficient (R) between humic substances and soil properties

	Ksat(cm hr^{-1})	MWD (mm)	WHC (g g^{-1})
HC (g kg^{-1})	0.604*	0.529*	0.511*
HAC (g kg^{-1})	0.551*	0.613*	0.471^{NS}
FAC (g kg^{-1})	0.810**	0.791**	0.538*

NS- significant at $p<0.05$. *significant at $p < 0.05$. **significant at $p<0.01$.
HC- humified carbon, HAC- humic acid-carbon, FAC- fulvic acid carbon,
Ksat- saturated hydraulic conductivity, MWD- mean weight diameter,
WHC- water holding capacity

DISCUSSION

Particle size distribution was dominated by the sand fractions. The high percentage sand observed in all the land use patterns could be attributed to the geology of the area. The geology of the area comprises of coastal plain sands and shale [20]. The higher percentage of sand fractions in the cultivated and fallow land is a good indication of low water holding capacity of the soils, which results into moisture stress as reported by [21] and this scenario encourages rapid leaching of nutrients from the soils beyond the rooting zones of the planted crops – a situation that threatens food security.

Generally, sand and silt contents decreased while clay content increased across depth from surface to subsurface soils. The increase in clay contents with depth under all land use types may be due to translocation of clay from surface to subsurface layers, which ultimately increase the proportion of sand and silt contents in the surface soil layers.

[22] found that land-use systems and soil depths significantly affected the sand, the clay and the silt fractions of the soils size distributions in Cameroon and even by land use alone. [23] reported that continuous cropping and intensive land use affected the particle size distribution and that these changes related to cultivation time, but the current finding is in contradiction to the result reported by [24], who found that land use systems had no effect on soil particles.

The acidity of the soils may be due to the nature of their parent material (coastal plain sands) as well as their highly weathered conditions. This observation corroborated with findings of [25] who reported that highly weathered soils of the coastal plain sands were acidic. However, the relatively higher acidity recorded at continuous cultivation compared to the other land use types, was probably as a result of leaching of the cations possibly induced by pulverization as a result of continuous tillage operations. This agreed with the report of [26] who stated that the leaching of the exchangeable bases due to excessive drainage increased soil acidity. Also, the higher acidity under continuous cultivation, compared to the other land use types, may be attributed to frequent plant uptake of the cations coupled with continuous crop harvesting (IITA, 1999). Conversely, the relatively lower acidity observed under forested and cultivation was possibly the result of reduced leaching of cations as well as the fall and decay of plant residues which returned absorbed cations to the soil through mineralization of the added OC. This agreed with the report of [27].

Organic carbon (OC) was influenced by land use types, with forest and cocoa plantation having the higher OC content due to the continuous addition of soil organic matter (SOM) and subsequent mineralization of the added SOM. [28] pointed out that the low level organic carbon in the cassava plot is a reflection of continuous cultivation and mineralization processes. The high OC content in forested and cocoa plantation could also be attributed to the fact that soils under those land use systems were always covered and had not been subjected to intense cultivation and use as in arable land use types [29].The current result is also in agreement with the findings of [30] who reported that changes in land use, such as conversion of natural forest to cropland, contributed to losses of soil organic matter. The result revealed that %OC decreased with depth. The decrease with depth could be due to accumulation of organic materials on the top soil and the low activities of micro organisms beneath the top soil.

The low bulk density values observed in forested soils is indicative of good structure with less compaction, reflecting the high organic carbon (OC) content. This phenomenon may be attributed to the decomposed plant litter that may have promoted soil faunal activities and may have played a major role in the build-up and stabilization of soil structure and as a result, improved soil granulation. These findings are in agreement with [31] who reported that soil organic matter improved soil structure and its stability. **Soil aggregation** – which reflects the arrangement of the primary sand-, silt-, and clay-sized particles into structural units defined as peds. Within their inherent limits (*i.e.* sands will always have fewer aggregates and lower aggregate stability than loam, clay loam, or clay soils), soils with an optimum level of aggregation will be more resistant to surface sealing, thus allowing more rapid water and air penetration. Soils with good aggregation will generally provide better soil – seed contact, which will result in more rapid transmission of water to the seed, quicker germination, and generally better and more uniform establishment of the desired crop. Soil aggregation is primarily influenced by tillage intensity and residue.

The relatively rapid saturated hydraulic conductivity values observed under continuous cultivation, compared to the other land-use types, were probably the result of the pulverization of the soil during tillage operations leading to the loosening of the soil and development of macropores confirming the report of [32].These values suggest high permeability which was reflected in the low moisture retention capacities under continuous cultivation. The higher water retention characteristics of soil under forested and cocoa plantation may be related to its high clay fraction and OC content which may have improved the stability of the soil macro aggregates thereby providing large charged surfaces for the attraction and retention of water molecules [33].

The greater stability observed in the forested and cocoa plantation land use at the soil surface layer occurred because in these land use systems there was more input to the organic matter in the soil, such as leaves, plant roots, root exudates, dissolved organic matter, and bioturbation. In previous studies [34]; [35], it has been shown that organic matter influences the soil structure and stability by binding soil mineral particles. The improved soil aggregation resulting from the accumulation of organic matter in the soil surface layer occurs due to the high specific surface area and cation exchange capacity of this layer. This allows more electrostatic bonds between soil particles, facilitating the formation of microaggregates and macroaggregates [36].

Micro aggregates (<0.25) were preferentially enriched in Humified carbon (HC) and Fulvic acid carbon (FAC) as compared with the large aggregates in both dry and wet sieves an indication that HC and FAC are better protected in micro aggregates than macro aggregates. Humified acid carbon concentrations were higher in macro aggregates than in micro aggregates. Comparing the results of the dry and wet sieves, it was observed that wetting caused a reduction in concentration of humic fractions in the aggregates.

Humic substances consist of the humic acid, fulvic acid and humin. These make up a large portion of the dark matter in humus and are complex colloidal supramolecular mixtures [37]; [38]. These organic substances play an important role from the agronomy point of view. They influence significantly the quality and productivity of the soil. In addition to the improvement of the soil's physical properties and moisture conditions, humic substances also show a high Base Exchange capacity, which is important for soil fertility [39].

This result indicates that land use is an important factor that controls the content and availability of humic substances in the soil. High content of humic and fulvic acids that was recorded in the Forested and cocoa plantation can be attributed to the organic matter returned to the soil through the leaf litter of trees. In a previous study conducted by [40] they reported that, vegetation influences the quality of soils under it, which also in turn influence the growth and performance of crops. According to [41] organic matter content, particularly the more stable (humic substances) increases the capacity of the soil to store water and sequester carbon from the atmosphere.

[42] maintained that land use and soil management practices significantly influence soil organic carbon dynamics and carbon flux from the soil. There was a marked decrease in the contents of humic acid and fulvic acid as a result of change in land use; Crop land recorded the lowest value of humic substances. This agrees with the findings of [43], who reported that conversion of grassland and forest plantations to arable cropping

results in the loss of 30 % of the soil organic carbon originally present in the soil. This shows that continuous cultivation of these soils can accelerate depletion of the soil organic carbon content. Fallow remains one of the traditional methods of land use management system that is used for soil fertility restoration through the buildup of soil organic matter. In this study it was noted that the contribution of six years fallow to the status of humic, fulvic acids and soil organic carbon was minimal. The natural forest and the cocoa plantation recorded a relatively high content of humic and fulvic acids due to accumulation and humification of organic matter under these land use types.

The positive correlation ($p < 0.05$) observed among humified carbon , humic acid carbon, fulvic acid carbon, saturated hydraulic conductivity (Ksat) and water holding capacity (WHC) suggests that the organic carbon fractions played a significant role in water movement in the soil, but specifically, the high positive correlation ($p < 0.01$) between FAC and ksat suggests FAC had a higher contribution to water movement in the soils studied. Humified carbon , humic acid carbon and particulate organic carbon correlated positively with MWD at ($p < 0.05$), the high positive correlation ($p < 0.01$) of FAC with Mean weight diameter (MWD), suggests that fulvic acid carbon played effective role and contributed significantly to aggregate stabilization of the soils studied. This goes to show that soils with higher concentrations of FAC are less susceptible to disintegration and less vulnerable to erosion. Fulvic acid carbon are very important bonding agents for soil aggregates [44].

The relationship between mineral-associated (stable fraction) soil organic carbon with various soil properties is a good indicator of soil health. Total organic carbon has been used as an indicator of soil fertility and productivity. The relationship between stable soil organic carbon and various soil properties in this study indicates that positive correlation exists. Some authors pointed out that this is attributed to the physical stability of aggregates in variable charge soils [34]; [35]. The mineral-associated soil organic carbon has been reported to be very important in increasing and/or maintaining soil quality and determining the soil's potential to act as an atmospheric CO_2 sink.

CONCLUSION

There exist differences across land use types in their potentials of storing organic carbon and humic substances in soils of Ikwuano. From the results it could be observed that, forest land had potentials for storing organic carbon of appreciable concentration. It also indicated that humic substances are sensitive parameters that reflect differences of soil aggregation and thus more reliable indicators to apply the most appropriate management practices to increase soil sustainability, productivity and soil quality.

Aggregate stability was found to be highest in the Forestland, an indication that organic matter content of the soil had a major influence in increasing the aggregate stability of the soils in the various land use conditions studied. It was observed that though HC and HAC correlated positively with MWD, the high correlation coefficient values of FAC in MWD, mean that Fulvic acid carbon fractions played effective role and contributed significantly to aggregate stabilization of the soils studied, thus a higher concentration of Fulvic acid carbon will ensure more stability of aggregates thereby enhancing its resistance to erosion and degradation.

The land management practices that encourage addition of organic matter to the soil are thus important in enhancing aggregate stability of soils thereby reducing land degradation due to soil erosion. This is because high aggregate stability of a soil results in resistance to soil erosion.

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