ORGANIC CARBON IN RELATION TO WATER RETENTION CHARACTERISTICS OF A TYPIC HAPLUDULT UNDER FOUR LAND USE TYPES AT NDUME IBEKU IN SOUTHEASTERN NIGERIA

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ABSTRACT

Soil moisture retention of an Ultisol was studied in relation to its organic carbon content under four land use types. The land use types were continuously cultivated arable land (ACC), forest land (FL), 3 – year grass fallow land (GFL) and oil palm plantation (OP). The experiment was laid out in a randomized complete block design (RCBD). A total of 36 auger and core samples were collected from the four land use types at 0 – 20cm depth. The data obtained were subjected to ANOVA, regression and correlation analyses. There was significant variation ($P \leq 5\%$) among the land use in water retention in the order FL > OP > GFL > ACC. The highest organic carbon storage (25.73 tons/ha) was observed at OP while the lowest (14.22 tons/ha) was at ACC. Significant negative relationship between organic carbon and water retention was observed in all the land use types. The coefficients of correlation (r) for FC, PWP and AWC under FL were - 0.927*, - 0.923*, and - 0.925*, respectively, and - 0.977**, - 0.977**, and - 0.973**, respectively, for FC, PWP and AWC under ACC while under GFL, it was - 0.978**, - 0.978**, and - 0.981** for FC, PWP and AWC, respectively, whereas under OPP, it was - 0.902*, FC, - 0.902*, and, - 0.897* for FC. PWP and AWC. Regression analysis suggested that organic carbon contributed 95.7%, 95.6% and 96.2% variations in FC, PWP and AWC, respectively, under GFL, while under OPP, it contributed 81.3%, 81.2% and 80.4% of the variations in FC, PWP and AWC, respectively. Also under ACC, it controlled 95.5% of variation in FC and PWP, while influencing 94.5% of variation in AWC. Variations in FC, PWP and AWC, under FL were controlled by organic carbon to the tune of 85.8%, 85.1% and 85.5%, respectively. In consideration of the relationship between organic carbon and soil moisture retention, efforts should be made to optimize soil organic carbon while ensuring adequate cover for tropical soils.

Keywords: Organic carbon, Water retention, Land use

INTRODUCTION

Organic carbon content and water retention characteristics are of great relevance in the overall fertility potential of soils (Oguike and Mbagwu, 2009). The moisture content of a soil influences seed germination, root growth and development, plants' resistance to pests and diseases, tillage operations, nutrients availability and crop yield (Nathalie, 2014). The organic carbon content of a soil impacts great influence on the soil water retention characteristics, water transmission, aggregation and aggregate stability, soil structure, as well as microbial biomass of soils (Mbagwu and Auerswald, 1999). These properties, however, are greatly influenced by human activities through land use and management such that their variability across soils follows systematic changes (Amusan *et al*., 2006; Mbagwu and Auerswald, 1999).

Oguike and Mbagwu (2009) further reported that changes in land use, such as conversion of natural forest to cropland, contributed to land degradation that manifested in losses of soil organic matter which altered the water retention characteristics of the soil. According to Malgwi and Abu (2011), continuous cultivation results in increase in sand fraction and bulk density, reduced organic carbon storage and water retention capacity as against bush fallow land use. Also, cropping usually results in losses of soil organic matter and soil aggregates, increase in bulk density and compaction, and this impacts great changes in the water retention capacity of the soil (Chisci and Zanchi, 1981). Kutilek (2005) reported that intensive cropping leads to disaggregation in surface soils because of decline in organic matter content due to repeated machinery movement, hence resulting in the reduced capacity of the soils to retain water at varying moisture constants.

Maintenance of a high concentration of soil organic carbon (SOC) is important for the aggregation of soil primary particles, increases water retention, nutrient supply, activities of soil organism with improvements in soil fertility and productivity, thereby ensuring long-term sustainability of an agroecosystem (Karlen *et al.,* 1997). However, soil organic carbon, depending on the nature could be hydrophobic or hydrophilic. Though the hydrophobic SOC compounds contribute greatly to water repellency in the soil, yet both the hydrophobic and hydrophilic SOC were reported to decrease the wettability of soils by increasing the soil – water contact angle which impedes the entry of water into the soil, thus decreasing water retention capacity of the soil (Leelamanie and Karube, 2009). This agreed with the report of Bisdom *et al.*, (1993) that hydrophobic SOC was found to be the dominant factor affecting soil water repellency. Furthermore, Dekker *et al.*, (1996) reported that in the presence of hydrophobic SOC compounds, the wettability of mineral particles of the soil was decreased due to increase in the soil – water contact angle, thus reducing the quantity of water retained in the soil.

The understanding of the relationship between soil organic carbon and water retention characteristics of soils under a given geological and a set of anthropological conditions is paramount for rational decisions on the effective management of the soils with a view of maintaining soil quality while improving crop productivity. The objective of this study, therefore, is to assess the relationship between organic carbon and water retention characteristics of soils under selected landuse types in a Typic Hapludult of the southeastern Nigeria.

MATERIALS AND METHODS

Study Area

The study was conducted at Ndume Ibeku in Umuahia North LGA, Abia State. The area lies within latitude $5^0 29^l$N to $5^0 31^l$N and longitude $7^0 30^l$E to $7^0 32^l$E with mean annual rainfall distribution of 2200mm (NiMeT, 2015). The area is characterized by rainy and dry seasons. The rainy season starts from March and extends to October with bimodal peaks in July and September, and a short spell of dryness in August. The dry season starts in November and lasts till February. The mean annual temperature is about 28^0C (NiMeT, 2015). The landscape is flat to gently undulating. Coastal plain sand is the dominant parent material in the area although there are localized regions of alluvial deposits. The soil of the area is of the order "Ultisols" and great group "Hapludults" according to the USDA soil taxonomy (Lekwa and Whiteside, 1986). The vegetation type is tropical rainforest. The common land use systems of the area include; bush fallow, oil palm plantation, grassland and arable farming cultivated to cassava, maize, yam and vegetables in a mixed cropping system. The arable soil is commonly managed by the use of mineral fertilizers often complemented with organic manure such as poultry droppings and swine waste.

LANDUSE TYPES

Four land use types namely arable farmland under continuous cultivation (ACC), oil palm plantation (OPP), forest land (FL) and 3 - year grass fallow land (GFL). The continuously cultivated arable land was sown to cassava (*Manihot esculentus*), yam (*Dioscorea spp.*) and pumpkin (*Telferia occidentalis*). The soil fertility was managed by the application of both mineral (NPK) and organic fertilizers (poultry droppings and swine waste). Weed control was by manual method of hoeing and hand-picking. The oil palm plantation was established for over 20years. There were also weeds (such as "Siam weed" (*Eupatorium odoratum*), mimosa plant (*Mimosa pudica*), etc, found in the plantation. However, the weeds were periodically cleared especially during the dry season to reduce excessive shade and competition with the oil palm trees. The forest land was secondary vegetation growing for over 20 years. The common tree species found in this forest include oil bean plant (*Pentaclethra macrophyllum*), African bread fruit (*Treculia Africana*), and bush mango (*Irvingia gabonensis*). Other plant species were shrubs and herbs like "Siam weed" (*Eupatorium odoratum*), etc. The grassland was a 1-year grassland previously sown to cassava. The tillage operations at the grassland when it was cultivated to cassava were done using plough, harrow and ridger attached to a tractor. The grass species was elephant grass (*Panicum maximum*).

Forest land and grass land were on a toposequence, and lie at the upper and mid slopes with mean altitudes of 142 and 127 masl, respectively while oil palm plantation and continuously cultivated land were on a near flat to gently undulating land with mean altitudes of 163 and 155 masl, respectively.

FIELD WORK

Soil Sampling

Under each land use type, auger and core samples were collected from nine observational points at 0-20cm depth using grid method of sampling. The samples were used to determine organic carbon and moisture contents of the soils in the various land use types.

Sample Preparation

The auger soil samples were air-dried and passed through a 2mm mesh for laboratory determination of SOC. The core samples were trimmed and soaked in water as soon as they were brought back from the field.

Laboratory Analyses

Field capacity (FC) was determined following the procedure outlined by Mbagwu (1991).

The percentage moisture at field capacity (FC) on dry mass basis was calculated as follows:

$$\%FC = \frac{M1-M2}{M2} X\,100 \ldots\ldots\ldots\ldots\ldots 1$$

Permanent wilting point (PWP) was determined by growing an indicator plant (*Zea mays*) in 500g of the soil sample in a metal can. Adequate moisture was applied to the plant until the third pair of leaves emerged. Then the top of the can was sealed with wax and kept outdoors until the plant wilted permanently. The soil moisture content at this point of permanent wilting was then determined as the permanent wilting point (Taylor and Ashcroft, 1972). The available water capacity (AWC) was obtained as the difference between the moisture contents at field capacity (FC) and permanent wilting point (PWP) as shown below:

%AWC = %FC - %PWP ……………… 2

Organic carbon was determined by the dichromate oxidation procedure of Walkley and Black as modified by Nelson and Sommers (1982). Total Carbon stored in the soil was calculated using the formula given below.

$C_T = C_F \times D \times V$ …………….. 3

where C_T is total organic carbon for the layer (metric ton), C_F is the fraction of carbon (percentage carbon divided by 100), D is density of the soil (kg/m^3) and V is the volume of the soil layer (m^3) (Peter, 2013).

Experimental design and statistical analysis

The experiment was laid out in a randomized complete block design (RCBD) involving four (4) land use types and nine (9) replicates of soils collected at each land use. The data generated from the study were subjected to correlation analysis and analysis of variance (ANOVA). The significant means were separated using Fisher – least significant difference at 5% probability level ($LSD_{0.05}$).

RESULTS AND DISCSSION

Water Retention Characteristics and Organic Carbon Storage of the Soils

The water retention characteristics and organic carbon storage across the various land use types are shown in Table 1. The water retention characteristics of soils varied significantly ($P \leq 0.05$) across the various land use types, except for soils in FL and OPP which were statistically similar.

Table 1: Water retention characteristics and organic carbon storage across the various land use types

Landuse types	FC (%)	PWP (%)	AWC (%)	OC (tha^{-1})
ACC	14.53	4.75	9.76	14.22
FL	24.69	11.31	13.38	24.69
GFL	18.10	7.05	11.10	19.68
OPP	24.44	11.15	13.28	25.73
LSD (0.05)	0.67	0.43	0.28	1.71

The highest amount of water retained at FC (24.69%), AWC (13.38%) and PWP (11.31 %) were observed under FL while the lowest at FC (14.53%), AWC (9.76 %) and PWP (4.75 %) were observed in ACC. The high water retention capacity of the soils under FL and OPP could be related to stability of the soils resulting from their undisturbed state. This may have improved the geometry and orientation of the soil pores as well as stabilizing the soil structure thereby promoting retention of water molecules within the soil matrix. This agreed with the report of Oguike and Mbagwu (2009) that undisturbed soils have better soil structure which imparted good water holding capacity in them. Conversely, the low capacity of the soil under ACC to retain water was perhaps as a result of excessive drainage due to frequent pulverization of the soil resulting from continuous tillage that may have loosened the soil, degenerated the structure and induced high porosity/low water retention (Malgwi and Abu, 2011).

The SOC accumulation of the soils under the different land use types varied significantly ($P \leq 0.05$). However, the SOC accumulation under OPP (25.73 tha^{-1}) and FL (24.69 tha^{-1}) were statistically similar. The highest organic carbon (OC) accumulation (25.73 tha^{-1}) was observed under OPP while ACC had the lowest value (14.22 tha^{-1}). The reason for the relatively high OC under OPP and FL may be related to their high biomass production which returned litter to the soil. Also, OC loss by oxidation was reduced due to adequate soil cover by the tree canopies as well as little or no disturbance to the soil (Holland, 2004). On the contrary, the low OC accumulation under ACC was perhaps a result of continuous loss of SOC by oxidation and aeration via continuous turning of the soil during frequent tillage. Also, the regular removal of plant biomass from the land at harvest depletes the residue return to the soil at ACC leading to the low organic carbon accumulation (Balesdent *et al*., 2000).

Relationship between organic Carbon and Water Retention Characteristics at the Land use Types

Correlation of organic carbon and water retention characteristics

Table 2 shows the correlation coefficients explaining the relationship between OC and water retention of the soils. In all cases, there was significant negative correlation of OC and water retained at FC, PWP and AWC.

Table 2: Correlation of organic carbon and water retention characteristics

	FL	ACC	GFL	OPP
	OC	**OC**	**OC**	**OC**
FC	-0.927*	-0.977**	-0.978**	-0.902*
PWP	-0.923*	-0.977**	-0.978**	-0.902*
AWC	-0.925*	-0.973**	-0.981**	-0.897*

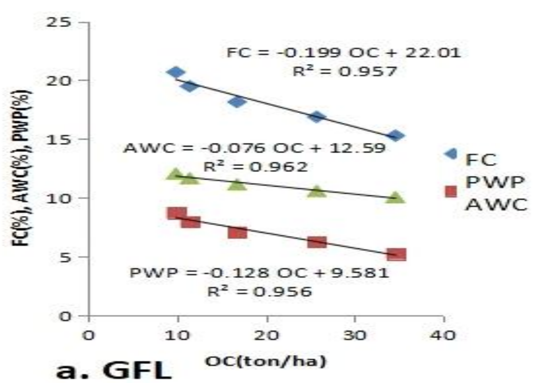
∗∗ (significant at 0.01), ∗ (significant at 0.05), n = 9

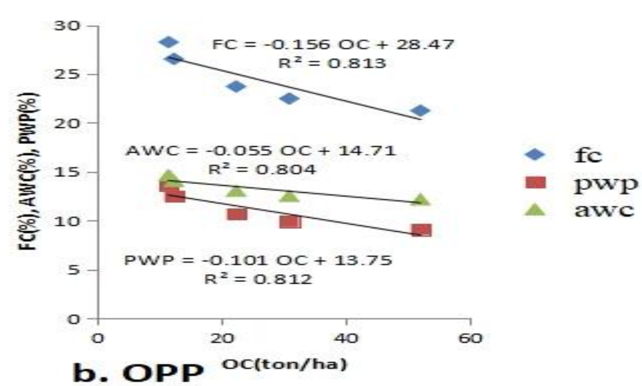
It may be affirmed that increase in OC accumulation of the soils under the land use types significantly decreased the water retention capacity of the soils. This finding contradicted the reports of Oguike and Mbagwu (2009), Malgwi and Abu (2011), and (Karlen *et al.,* 1997) who reported a significant positive relationship of organic carbon and water retention characteristics of the soils studied. However, Leelamanie and Karube, (2009) showed that OC can be hydrophobic or hydrophilic depending on its nature. They further explained that although the hydrophobic OC compounds contribute greatly to water repellency in the soil, both the hydrophobic and hydrophilic OC were noted to decrease the wettability of soils by increasing the soil – water contact angle which impedes the entry of water into the soil, thus decreasing water retention capacity of the soil. It could therefore be inferred that the negative relationship between organic carbon and the water retention properties of the soils was probably a consequence of the likely hydrophobic nature of the OC compounds contained in the soils. These hydrophobic OC compounds may have increased the repellency of the soils to water, impeded the wettability of the soils and decreased the retention of water in the soils. This agreed with the report of Bisdom *et al.,* (1993) that hydrophobic OC was found to be the dominant factor affecting soil water repellency and decreased water retention in the soil.

Regression of organic carbon and water retention characteristics

Figure 1(a – d) shows the coefficients of determination (R^2) of the regression between organic carbon and the water retention characteristics at the various land use types. It revealed that there was a negative linear relationship between OC (independent variable) and water retention characteristics(FC, AWC and PWP) (dependent variables). For any unit increase in OC, there were 0.199, 0.156, 0.621 and 0.247% decrease in FC under GFL, OPP, ACC and FL, respectively.

The values of the coefficient of determination revealed that the total variability in FC contributed by OC was highest under GL (95.7%) and lowest under OP (81.3%). The Figure further showed that for every unit increase in OC, AWC decreased by 0.076, 0.055, 0.223 and 0.089 under GFL, OPP, ACC and FL, respectively. However, the total variability in AWC contributed by OC was highest under GFL (96.2%) and lowest under OPP (80.4%). Also, for any unit increase in OC, PWP decreases by 0.128, 0.101, 0.401 and 0.146% under GFL, OPP, ACC and FL, respectively.





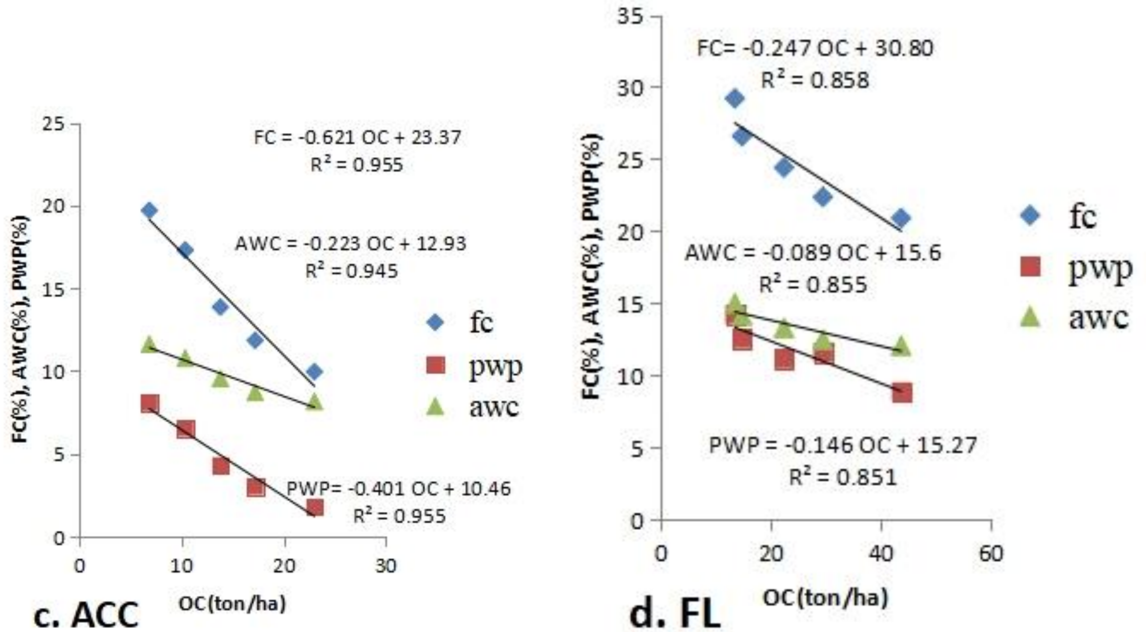


Fig. 1(a – d):Regression of organic carbon (independent variable) and water retention characteristics (dependent variables)at the land use types

Consequently, the total variability in PWP contributed by OC was highest at GFL (95.6%) and least at OPP (81.2%). The values of coefficient of determination showed that OC greatly influenced the decrease in water retention characteristics under GFL compared to the other land use types. This could be predicted on the possible presence of more hydrophobic OC in the soil under GFL than the other land use types; hence, any slight increase in the OC at GFL, there was significant decrease in the water retention capacity of the soil. Conversely, the weak influence of OC on the water retention characteristics of the soil at OPP could be inferred on the possible high accumulation of the hydrophilic type of OC than the hydrophobic type; thus, increase in the accumulation of such OC at OPP would not have considerable decrease the quantity of water retained in the soil at OPP. These corroborated the report of Leelamanie and Karube, (2009) that soils with higher accumulation of the hydrophobic OC than the hydrophilic type had greater capacity to decrease the wettability of soil mineral particles thereby decreased the retention of water molecules in a body of soil. Dekker *et al.*, (1996) also agreed with the report by stating that in the presence of hydrophobic OC compounds, the wettability of mineral particles of the soil was decreased due to increase in the soil – water contact angle, thus reducing the quantity of water retained in the soil.

It is therefore suspected that soils could be unique with respect to the nature of the relationship between their organic carbon content and water retention characteristics. This may probably be attributed to the variation in the quantity, nature and composition of organic carbon accumulated in the soils.

CONCLUSION AND RECOMMENDATION

There was a general decrease in the water retention characteristics with increase in organic carbon storage of the soils under the land use types studied. This, therefore, indicates a negative relationship between organic carbon storage and the capacity of the soils at the land use types to retain water at the varying moisture contents. The level of significance of these negative relationships was greatly influenced by land use types and / or soil management practices including the composition of the vegetation at the land use type. Hence, in an effort to improve the organic carbon storage of the soils, there must be need to adopt agronomic strategies (such as provision of surface cover by mulching and cover cropping) to prevent excessive water loss from soil via evaporation.

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