Soil Organic Carbon Dynamics under different plantation crops of different ages in a Tropical Oxic Paleustalf

J S Ogeh *
Department of Soil Science,
University of Benin,
Benin City,
Nigeria
E-mail: joseph.ogeh@uniben.edu

R R Ipinmoroti
Cocoa Rsearch Institute of Nigeria,
Ibadan
E-mail: ipinmoroti2r@ymail.com

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Abstract

Increasing the carbon sequestration potential of the soil is one of the ways to address the increasing build-up of greenhouse gases especially carbon dioxide.A study was conducted to assess the organic carbon pool under Young and Old tree plantations at Uhonmora, Edo State, Nigeria. The plantation species included *Anacadium occidentales*, *Theobroma cacao* and *Coffea robusta*. Result showed that SOC pool was the maximum in the old cashew plots (45 years) and decreased in the following order SOC in young cocoa (1 year) > young coffee (6 years)> old cocoa (46 years) > young cashew (2 years) > old coffee (20 years). Results also indicated that differences in SOC pool under different plantation were statistically significant ($p \leq 0.05$). The *A. Occidentals* plot had 6.36g/kg soil organic carbon after 45 years in this study and it was found to store more than double SOC pool when compared to other plantations. The soils also vary in the N contents. The young cashew plot was low in N content but adequate for other plots. Using the SOC as indicator, the soil organic matter content needs to be improved upon for sustainable productivity. Soil texture in all the plantations was loamy sand. Soil organic carbon content variation across the plantations with age of establishment will necessitate the need to produce a suitable habitat for microorganisms which are involved in litter degradation process. However, there was strong correlation between soil organic carbon and nitrogen ($r=0.96$; $p \leq 0.05$) across the plantations. Prediction of soil organic carbon in any of the plantation was indicated by the linear regression study.

Keywords: *Soil organic carbon, plantation crops, different ages, tropics, cashew, oxic paleustalf*

**For correspondences and reprints*

1. INTRODUCTION

Plantation agriculture is an important form of land-use in the tropics and in many countries the area under plantation crops has expanded rapidly in the past decades (Hartemink, 2003). InNigeria,plantation crops are crops of economic importance and they consist of oil palm, rubber, cashew, oranges, mango, cocoa, coffee etc. One common feature of these crops is that they can be grown for many years while harvesting continues until probably when yield begins to decline. Every year these crops take nutrient from the soil and some are returned back through litter fall and decomposition of these litter. Good agricultural management practices on young plantations of these crops will require the use of soil surface mulching by the use of organic wastes and cover crops under special cropping systems that are compatible with each of the plantation crops for successful plot establishment and better growth performance of the young seedlings. At the Cocoa Research Institute of Nigeria (CRIN), various cropping systems have been found suitable and adaptable to the various crops which includes: cocoa/plantain/maize, cocoa/oil palm in hollow-square arrangement, cocoa/plantain/rice for cocoa (Famaye, et al., 2010); coffee/oil palm, coffee/melon, coffee/soybean, coffee/maize for coffee (Famaye, et al., 2012) and cashew/maize, cashew/cowpea, cashew/soybean, cashew/plantain for cashew (Famaye and Adeyemi, 2011). The organic wastes, mulch and vegetative covers would help to reduce surface water loss through intense evaporation that could result through the high sun isolation and heat that is characteristic of tropical conditions, coupled with the changing climatic conditions.

Soil organic carbon forms an integral part of soil organic matter and these can be used to predict amount of soil organic matter in the field. The litter fall from these plantations may have ability to increase soil organic carbon (Yang *et. al.* 2005; Njar *et. al.* 2011; Lu *et. al.* 2013). These plantation crops may also have a capacity to sequester C due to some large scale planting of these crops in the southern part of Nigeria. Thus large scale planting of these crops and biomass production could contribute to soil C sequestration. However, the amount of soil C sequestered in these plantation crops is inadequately understood and quantified. It is very necessary to measure the amount of soil organic C in these crops and be able to estimate their content at specific ages. Enhanced sequestration of atmospheric CO_2 in the soil, ultimately as stable soil organic matter, provides a more lasting solution than sequestering CO_2 in standing biomass. No study has been undertaken to estimate the soil organic carbon pool in these young and old plantations in the forest/savana transition zone. Although some investigations have been carried out and data generated on the soil organic carbon pool in forest stands (Ogeh 2014). Therefore, this study was conducted to estimate SOC pool under different plantation crops of different ages (young and old) and predict amount of soil organic carbon over a period of years in any of the plantation.

2. MATERIALS AND METHODS

The experimental site was located at Cocoa Research Institute of Nigeria (CRIN) Uhonmora Station (6^O 53'N and 5^O 58'E). Each plot of 1.0 ha were demarcated into sub-plots of 0.25 ha size. Soil samples were randomly collected from each of the sub-plots representing a replicate making a total of four for each of the plantation at 0 – 20 cm soil depth. Each soil sample from a sub-plot was a composite of three soil cores of surface 0-20 cm soil depths.The plantations were: very young cocoa plot established in 2012 (2 years) and very old plot established in 1967 (47 years); young coffee plot established in 2007 (7 years) and old coffee plot established in 1993 (21 years); young cashew plot established in 2011(3 years) and old cashew plot established in 1968 (46 years). Variation in ages was due to difference in area available under particular crop species.

The soil samples were air dried, passed through 2-mm sieve and the samples per sub-plot were thoroughly mixed to form a uniform composite sample. Four composite samples were obtained per plot for a total of 24 composite samples for the 6 plots. The composite samples were processed in the laboratory and analyzed for Textural analysis like sand, silt and clay as well as physicochemical properties like pH (H_2O), EC, total N. Organic carbon (OC), Soil particle size distribution was determined by Bouyoucos hydrometer method, while the soil pH was in soil/water ratio of 1:2.5 (Jackson, 1962). Soil total N was determined by micro-kjeldah method (Bremmer, 1996). The SOC was determined by wet dichromate oxidation method (Nelson and Sommers, 1982).The electrical conductivity was determined in 1:2 soil/water ratio using conductivity bridge (Rhoades, 1982). Because the input of organic matter is largely from above ground litter, forest soil organic matter tends to concentrate in the upper soil horizons, with roughly half of the soil organic carbon of the top 100 cm of mineral soil being held in the upper 30 cm layer. The carbon held in the upper pro-file is often the most chemically decomposable, and the most directly exposed to natural and anthropogenic disturbances (IPCC 2003). Therefore, soil organic carbon pool was estimated up to the depth of 20 cm in the present investigation. Data obtained were subjected to statistical analysis using Genstat release 8.1. ANOVA were performed by taking age and crop management systems into consideration (Cocoa, Coffee and Cashew as independent variables and dependent variables included SOC). Descriptive statistics was used in describing the particle size. Correlation was performed in order to detect the relationships between soil carbon and other soil parameters. Linear regression equations were also calculated to predict soil organic matter in each of the plantation.

3. RESULTS AND DISCUSSION

Soil particle size analysis:

The soils of the plantations varied in their particle size fractions. Sand content ranged from 757-857g/kg, silt was 111-191g/kg while clay was 32-52 g/kg (Table 1). The soils were generally loamy sand in texture, with silt + clay values range from 143-243 g/kg soil, which falls below 320 g/kg soil considered optimal for better water retention for most tree crops (Egbe, *et al*., 1989). This indicates that the soils could not retain and supply sufficient water to meet the needs of the plantation crops without irrigation, most especially, over a long period of dry spelt. Sufficient water supply, most importantly during flower and fruit settings for the crops, is very critical. The failure of water supply at such a time will lead to flower and fruit abortions with resultant low fruit yield. The plantation soils could be better managed by making sure that plantation canopies are covered by not allowing missing stands, while the plantation floor is covered with leaf litter falls to serve as preventive measures against loss of soil water through evaporation (Loria, 1999; Ogunlade and Iloyanomon, 2009).

Table 1: Textural class for plantation crop grown soils

Plantation	Sand	Silt	Clay	Texural class
	←---------------g/kg------------->			
Young cocoa	827	141	32	Loamy sand
Old cocoa	857	111	32	Loamy sand
Young coffee	757	191	52	Loamy sand
Old coffee	837	126	37	Loamy sand
Young cashew	817	141	42	Loamy sand
Old cashew	842	116	42	Loamy sand

Soil organic carbon content

The soil organic carbon contents were higher for the young cocoa and coffee plantations compared with the old plantations (Table 2), while the value was higher for the old cashew plantation compared with the young cashew plot. The cropping history of the plantations indicated that the young cocoa and coffee plantations were established from the clearing of secondary forest, for which the soil organic carbon must have accumulated over the years, while the young cashew plot was established from plot under continuous arable cultivation for 3 years and majorly covered by elephant grass, with little or no soil organic carbon accumulation expected. The lower SOC in the old cocoa plantation might be due to the relatively slow rate of cocoa leaf litter materials decomposition (Owusu-Sekyere, *et al*, 2006; Triadiati, *et al.*, 2011), cocoa leaf form about 80 % of the heavy mat of leaf falls, with subsequent low rate of addition of organic carbon to the soil reserve. The lower SOC (1.34g/kg) for the old coffee plantation may probably stem from the long period of oxidation of organic materials than being added to the soil over the years. The geometry of coffee allows for open spaces between coffee plant inter rows which are prone to rainfall intensity impact and loss of materials by surface run-off and seepage(Grossman, 2003; Altieri, 1999).

On the order hand, the relatively high SOC (6.36g/kg) for the old cashew plantation must have resulted from the dense canopy coverage of the plantation by the cashew plants. This must have made the environment conducive for steady decomposition of the plant debris and accumulation of the products in the soil for increased SOC. This was not the situation for the young cashew plantation that has no canopy developed and equally prone to erosion factors

Soil pH

The soil pH values between the young and old plantations differ across the crop types (Table 2). The soil of Uhonmora area is characterised with pH value of 6.5. For the cocoa plantation, the young cocoa still maintained the native pH value of 6.5, while the older cocoa plantation has its soil pH increased to 6.9. This indicates an improvement on the soil pH condition, which may probably be due to the thick layer of leaf mat that is peculiar of old cocoa plantations. The leaves help to cover the soil surface, reduced erosion and under-go gradual decomposition which must have helped to increase the soil pH level.

The young and old coffee plantations with pH values of 5.8 and 5.9 are similar. This showed that similar chemical reactions are taking place in the two plantation soils. Coffee plant geometry allows for interplant row spaces which are left bared and makes rainfall impacts to be seriously felt and soil surface layer prone to erosion hazards and seepages. The young and old cashew plantations differ greatly in their soil pH values. This is expected in that soils under cashew cultivation are noted for their acidic conditions with pH range of 4.5 – 5.5 (Owaiye, 1989). The older the cashew plantation is, the more acidic the soil condition becomes. This results from built up of natural biochemical exudates from cashew roots in the rhizosphere that makes the soil to be acidic. Hence, the old cashew plant with pH 5.1 compared with 6.1 for the young cashew plot showed that greater amount of root exudates have been released over the years by the cashew plants in the old cashew plot compared with the young cashew plot. The old cashew plot therefore need soil amendments to increase the soil pH value from time to time by application of liming materials, slurry wastes and manures (Onwuka, *et al.*, 2009; Nikoli and Matsi, 2011; Whalen, *et al.*, 2000).

Soil EC

The soil electrical conductivity ranged from 12.1-30.6 (Table 2). The electrical conductivity (EC) was highest for the young cocoa plantation and least for the old coffee plantation. The differences of electrical conductivity as seen in the different plantation at different ages were similar to the findings of Terra *et. al.*, 2004. In their study topography, silt content and electrical conductivity explained up to 50% of the Soil Organic Carbon variability (Terra, *et al.*, 2004). They also suggested that terrain attributes and EC survey can be used to differentiate zones of variable SOC which may be used as benchmarks to evaluate field-level impact of management practices on Carbon sequestration.

Soil total N contents

The total N content range of 0.12-0.22 g kg^{-1}(Table 2) of the soil for the cocoa and coffee plantations were above the critical levels of 0.09 g kg^{-1} which is ideal for cocoa and coffee production. However, the values of 0.12 and 0.14 g $kg^{-1}$for the old plantation of coffee and cocoa respectively showed that adequate and proper management techniques that will enhance the N built up is necessary to avoid N inadequacy in the long run, which could result from harvest of berries for coffee and pods for cocoa. A harvest of 1.0t of cocoa leads to a loss of over 45 kg Nha^{-1}(Wood and Lass, 1985) while for coffee; it is about 54-57 Kg Nha^{-1}(Mamani-Pati, *et al*, 2012). The young cocoa and coffee plantations do not need N fertilizer application until the commencement of pod and berry harvest, at which time, the amount of N fertilizer need would be based on yearly harvest removal.

Table 2: Physico chemical properties of the plantation crop grown soils

Plantation	pH (H_2O)	Org. C	N	EC
		←------- g/kg ----→		dSm^{-2}
Young cocoa	6.5a	2.79b	0.22b	30.6a
Old cocoa	6.9a	1.54d	0.14c	20.7bc
Young coffee	5.8c	2.75b	0.22b	15.2c
Old coffee	5.9c	1.34c	0.12c	12.1d
Young cashew	6.1ba	1.38c	0.07d	20.3bc
Old cashew	5.1d	6.36a	0.24a	22.3b

Means followed by the same letters within columns are not significantly different using Duncan Multiple Range Test (DMRT) at 5% probability

On the other hand, total N content for the old cashew plantation was well above critical value of 0.1 g kg^{-1} while that of the young cashew was far below critical value. The young cashew plot therefore needs N supplementation. The variation in the soil nutrient contents across the plantation types and age of establishment necessitate the need for routine soil nutrient assessment in order to have the correct soil nutrient status for proper and balanced soil nutrients, for healthy crop growth and optimum yield.

Prediction equation for soil organic carbon in the plantations (Linear regression equation)

For Soil Organic Carbon (SOC) in Cocoa:

$Y= 24.924x + 70.924$

For Soil Organic Carbon (SOC) in Coffee:

$Y= 8.298x – 21.495$

For Soil Organic Carbon (SOC) in Cashew:

$Y= 34.433x- 23.867$

where Y is soil organic carbon to be predicted and x is age

Table 3: Pearson correlation coefficient of soil organic carbon and other soil parameter

Parameter	Significance
EC	Ns
N	0.9616*
pH H_2O	Ns

* Significant at $P \leq 0.05$

4. CONCLUSION

The investigation revealed that there are great differences in the soil organic carbon contents between the old and new plantations across the crop types. SOC was the maximum in the old cashew followed by young cocoa and young coffee. Differences in SOC under different plantation were statistically significant. The results showed the comprehensive estimates of the SOC under different plantation covers. Information generated from this study can be used as a benchmark for future work to estimate the changes in SOC pool in these land uses.The measurement of soil organic carbon (SOC) content at the onset of a trial provides a baseline from which to calculate the impact of imposed management treatments on rates of SOC change. Initial SOC measurements can also be useful to verify that starting SOC values are similar or not. Based on the above, we argue here that the soil build up or loss in different plantation crops may not be the same; that predicting the amount of soil organic carbon at any point in time in terms of years may follow the same trend; that the same management may be applied to building up SOC in the plantation crops.

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