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Soil organic carbon fractions as affected by land use in the Sourthern Guinea Savanna ecosystem of Adamawa State, Nigeria

G. Y. Jamala[1]* and D. O. Oke[2]

[1]College of Agriculture, Ganye, Adamawa State, Nigeria.
[2]Federal University of Technology Akure, Ondo State, Nigeria.

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This study was conducted to evaluate the effects of three land use management (natural forest, crop land and natural fallow) and soil depth on soil organic carbon fractions. The study was carried out in Toungo and Jada, Adamawa State, Nigeria. Three transects were cut 100 m apart in each of the study sites and four sampling plots of 20 m × 20 m in dimension were laid in alternate positions along each transect at 50 m interval. Soil samples were collected at depth of 0-15, 15-30, 30-45 and 45-60 cm and at three points along the diagonal of each plot using a 3 cm diameter soil auger. Soil contents of mineral-associated organic carbon fraction were higher than the particulate organic carbon pool in all land use management systems. Surface soil (0-15 cm) total organic carbon (TOC) content was highest under the natural forest (1.94%) and lowest in the cropland (1.46%). From the results it was noted that, natural forest had capacity for increasing soil organic carbon to an appreciable concentration. Fallow contribution to soil organic carbon was minimal. This could be attributed to several factors such as wind erosion, grazing, bush burning and cutting of vegetation for fuel wood. The contents of total, particulate and mineral-associated soil organic carbon was significantly influenced by land use management and soil depth. All the different land use types showed highest accumulation of the various carbon fractions in the surface layer (0-15cm). This high level of organic carbon stock in the surface layer could be due to the slow of mixing of the soil.

Key words: Land use, carbon fraction, forest, mineral, particulate organic carbon.

INTRODUCTION

Soil stores two or three time more carbon than that which exists in the atmosphere as CO_2 and 2.5 to 3 times as much as that stored in plants in the terrestrial ecosystem (Post et al., 2000; Houghton and Skole, 1990). Schimel et al. (2000) pointed out that the knowledge of the spatial distribution of soil organic carbon is an important requirement for understanding the role of soils in the global carbon system.

Soil organic matter is composed of different compartments which differ from each other in biochemical composition, biological stability and carbon turnover rates (Paustian et al., 1992). Both labile, mineral associated and humified soil organic fractions may show different susceptibility to land use and management effects. In cold and/or semiarid region, the carbon stocks in labile particulate soil organic carbon fraction constitute

*Corresponding author. E-mail: kindnessgailyson@gmail.com. Tel: +234-8055021352, -8022626249.

carbon (Chan, 1997; Franzluebbers and Arshad, 1997), and is the most affected by agricultural practices. A study conducted by Bayer et al. (2006) shows that particulate soil organic carbon usually ranges between 30 to 40% of total organic carbon in most of Brazilian soils. Hot and humid environment favours microbial activity that leads to intensive decomposition and humification of labile fractions (Bayer and Bertol, 1999).

The extent to which land use management influences soil organic matter (SOM) dynamics can be best evaluated by separating SOM into fractions. These include particulate organic carbon (POC), mineral-associated organic carbon (MOC) and the humified soil organic carbon (HA, FA and Humin). The POC consists of partly decomposed plant and animal residues with a rapid turnover; it is more responsive to management factors and it is believed to make a greater contribution to nutrient cycling (Janzen et al., 1992). Great stability of mineral-associated soil organic carbon in highly weathered soils, which may be important in maintaining and restoring soil quality, determines the soil potential for acting as an atmospheric CO_2 sink in tropical and subtropical regions (Parfitt et al., 1997).

Soil organic matter is an important factor in evaluating management system quality (Doran and Parkin, 1994). In warm and wet tropical and subtropical climatic regions, rapid soil organic matter (~ 58% Carbon) decline occurs under conventional management systems involving intensive soil disturbance (Tiessen et al., 1992; Parfitt et al., 1997). The soil organic matter degradation has negative effects mainly on cation exchange capacity, nutrient availability, aggregate stability and microbial activity (Bayer and Mielniczuk, 1999).

Several studies on soil organic matter dynamics focused on its absolute amount in the savanna ecosystem. It is important also to investigate the effects of land use management and soil depth on the labile (particulate) and stable (mineral-associated) soil organic matter fractions (Scholes et al., 1997). This study therefore, examines the effects of three land use management (natural forest, cultivated land and natural fallow) and soil depth on total soil organic carbon stocks and carbon stocks in labile and stable fractions.

MATERIALS AND METHODS

The study area

Adamawa State lies between latitudes 8° N and 11° N and longitude 11.5°and 13.5°E. The State shares border with Gombe State to the North, and Borno State to the North East, while to the West it is bordered with Taraba State as well as the Republic of Cameroon to the East. Adamawa State has a total area of 39,742.12 square kilometers. The study was carried out in and around Gumti sector, the northern half of Gashaka-Gumti National Park, covering Toungo and Jada local government areas of Adamawa State (Figure 1). The area received an annual rainfall of 1000–1600 mm. Rainfall distribution is unimodal, with much of the rain falling between April and November. Day time temperatures may drop below 18°C at higher altitudes and gradually rise to 40°C. The rainy season is followed by a dry season. During this period, the area comes under the strong influence of the hammattan (November and March) a dry dusty wind blows from Sahara Desert and temperatures may be significantly cooler (GGNP, 2010; Adebayo, 1999).

Site selection and sampling procedure

Soil samples were collected from three sites under different land use management: natural forest, crop land and a natural fallow. The forest consisted of southern guinea vegetation; the crop land had been under cultivation for approximately 27 years and the fallow land had been under fallow condition for about 7 years. The natural forest is strictly restricted as a National Park and hence no crop cultivation. The crop land is extensively cultivated with crops such as Maize, Sorghum, Cowpea, Arachis *hypogeal,* Yam and livestock grazing is usually carried out on the site. Fallow land was left under natural fallow, crops cultivated before fallow includes *Arachis hypogeal,* Yam, Maize, Sorghum and Cowpea. Livestock grazing and fetching of fuel wood also takes place.

Systematic strip sampling was employed in laying out the plots. Three transects were cut 100 m apart in each of the study site and four sampling plots of 20 × 20 m in dimension were laid in alternate positions along each transect at 50 m interval. Soil core samples were collected at a depth of 0-15, 15-30, 30-45 and 45-60 cm and at three points along the diagonal of each plot using a 3 cm diameter soil auger. Samples from each plot at each depth were bulked separately and the composite soil samples taken to the laboratory and analyzed for total, particulate, mineral-associated soil organic carbon and other physico-chemical soil properties.

Physical fractionation of soils into particulate and mineral size fractions

The process of soil physical fractionation was based on the methodology developed by Cambardella and Elliott (1992). 50 g of 2 mm soil sample was transferred into a 250 ml sample bottle and 105 ml distilled water added. Soil suspension was then washed through a 53 mm sieve and the coarse fraction was separated. The soil samples above the 53 µm sieve, were considered particulate SOM while, those that pass through the sieve was mineral associated SOM. The particulate (≥53 µm) and mineral associated (<53 µm) soil organic matter fractions were dried in an oven at 75°C, and analyzed for organic carbon using the wet oxidation method.

Organic carbon determination in the various fractions

Organic carbon was determined in the bulk soil, (≥53 µm) and (<53 µm) soil fractions as total organic carbon (TOC), particulate organic carbon (POC) and mineral organic carbon (MOC) respectively, using the wet oxidation method of Walkley and Black (1934).

Statistical analyses

Data collected were subjected to analysis of variance (ANOVA) procedure for Randomized Complete Block Design (RCBD). The land use types constituted the treatments while soil depths constituted the blocks. The Statistical analysis was performed with SPSS (V. 18), mean separation was performed with Duncan's Multiple Range Test (DMRT) at $p<0.05$.

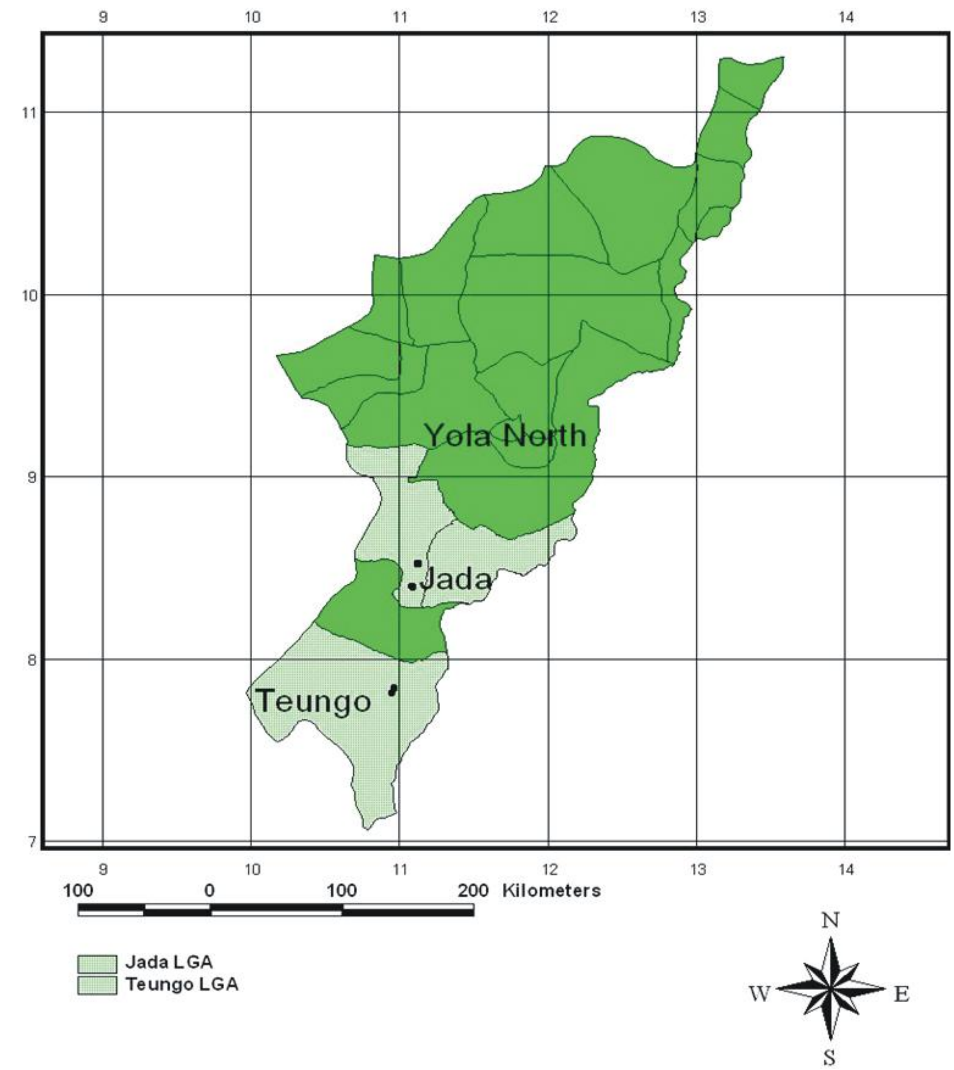

Figure 1. Map of Adamawa State, Nigeria, showing the study sites.

RESULTS AND DISCUSSION

Effect of land use management on total soil organic carbon (TSOC)

Table 1 presents the results of particle size distribution and soil texture of the various soil depths in the study sites. The soil texture in the natural forest and fallow land ranges from sandy loam to clay loam and loam to clay loam in the crop land. Compared to natural forest site, land cultivation led to a decrease in total soil organic carbon (Table 2). In the fallow land soil organic carbon status was lower than the values obtained in both natural forest and crop land. Total soil organic carbon in the natural forest was approximately 8 and 15% higher compared with crop land and fallow land respectively. This finding corroborate the report of Alexandra and Jose (2005), 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. Loss of soil organic matter can therefore, reduce soil fertility, degrade soil structure and lower water holding capacity, ultimately leading to desertification. Bationo et al. (2003) noted that one single most important biophysical constraint to food security in the West African savanna has been identified to be soil fertility degradation.

In the savanna agro ecosystem, the bush fallow remains one of the traditional methods that are used for soil fertility restoration through the buildup of soil organic matter. In this study it was noted that the contribution of seven years of fallow to the status of total soil organic carbon was minimal. This might be attributed to several factors such as livestock grazing, incidence of annual bush burning and cutting of vegetation for fuel wood which is more frequent in the study area.

Table 1. Particle size distribution and soil texture.

Site	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture
Natural forest	0-15	58.92	29.64	11.44	SL
	15-30	51.84	30.72	17.44	L
	30-45	39.84	18.72	41.44	CL
	45-60	34.2	19.64	46.16	CL
Crop land	0-15	39.28	42.92	17.80	L
	15-30	34.2	19.64	46.16	CL
	30-45	31.28	33.28	35.44	CL
	45-60	21.84	32.36	45.80	CL
Fallow land	0-15	71.28	19.28	9.44	SL
	15-30	65.28	15.28	19.44	SL
	30-45	44.92	17.64	37.44	L
	45-60	31.28	33.28	35.44	CL

NB: SL=Sandy Loam, L=Loam, CL=Clay Loam.

Table 2. Influence of land use management on total soil organic carbon (%).

Soil depth (cm)	Natural forest	Fallow land	Crop land
0-15	1.94[a]	1.55[b]	1.46[c]
15-30	1.33[a]	0.54[c]	1.12[b]
30-45	0.70a	0.54[b]	0.55[b]
45-60	0.70[a]	0.34[c]	0.54[b]

Means with the same letter along the rows are not significantly different (Duncan's Multiple Range Test P< 0.05).

The increasing pressure on agricultural lands in the savanna is making it impossible to continue with bush fallow. Currently, fallow periods have either been shortened or totally replaced by continuous cultivation. In addition to these, most lands of the dry savanna regions are highly vulnerable to wind and water erosion resulting in soil degradation. In a 12-year fallow study, Bayer et al. (2000) found that, the increase in C and N stocks were minimal. Scherr (1999) pointed out that proper management of soil organic matter is important to food security and the protection of marginal lands.

Effect of land use on particulate and mineral-associated soil organic carbon fractions

The values obtained for mineral-associated soil organic carbon pool (the stable form) were relatively higher than the particulate soil organic carbon pool (the labile pool) (Table 3) in all land use management systems. This indicates that a high proportion of total soil organic carbon is made up of mineral-associated soil organic carbon pool in advanced humification form. The higher proportion of carbon in mineral-associated fractions than in labile fractions is probably due to climatic conditions favorable to organic matter decomposition (mainly labile fractions), as well as to physical and chemical stability of mineral-associated soil organic carbon. In tropical and subtropical soils, Parfitt et al. (1997) noted that variable charge mineral and soil organic matter interactions can promote a great soil organic matter protection against biological decomposition. Also, Bayer et al. (2001) found that the carbon pool in mineral-associated soil organic matter increased several times more than the particulate organic matter fraction and attributed it to greater physical recalcitrance of mineral-associated soil organic matter to biological decomposition.

The content of particulate organic carbon was observed to be low in almost all the land use management systems. This could be the results of increased rate of humification in these soils. Bayer et al. (2006) reported that the content of particulate soil organic carbon was lower than the mineral-associated soil organic carbon in the most Brazilian soils, this usually ranged between 30 and 40% of total soil organic carbon. According to Adejuyigbe et al. (2000), the particulate organic matter is a more labile fraction of the soil organic matter which is the most readily formed and when it decomposes, it serves as an important substrate for mineralization process in the soil. The level of this fraction therefore, could be an essential determinant of the fertility status of savanna soils. Bescansa et al. (2006) stated that,

Table 3. Influence of land use management on Particulate and Mineral-Associated Soil Organic Carbon.

Soil depth (cm)	Natural forest	Fallow land	Crop land
	Particulate soil organic carbon (%)		
0-15	0.77[a]	0.68[b]	0.50[c]
15-30	0.62[a]	0.24[c]	0.44[b]
30-45	0.39[a]	0.24[c]	0.31[b]
45-60	0.39[a]	0.11[c]	0.31[b]
	Mineral-associated soil organic carbon (%)		
0-15	1.15[a]	0.87[c]	0.95[b]
15-30	0.70[b]	0.29[c]	0.75[a]
30-45	0.31[a]	0.23[b]	0.23[b]
45-60	0.31[a]	0.29[a]	0.23[b]

Means with the same letter along the rows are not significantly different (Duncan's Multiple Range Test P< 0.05).

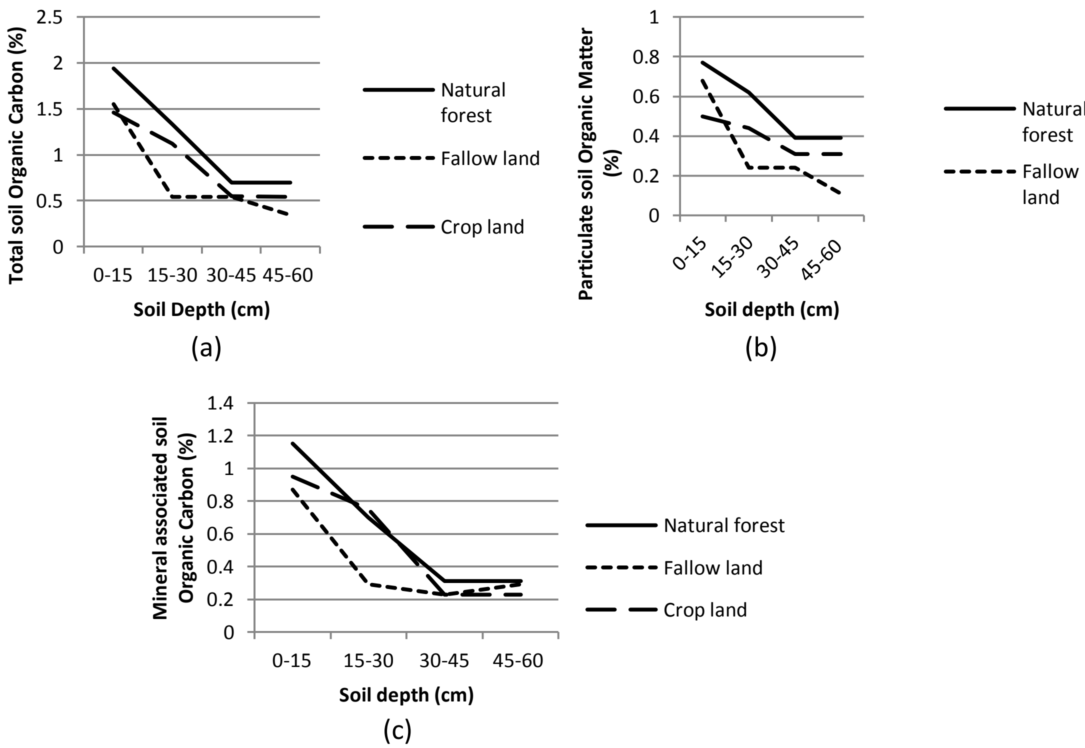

Figure 2. Changes in (a) total, (b) particulate and (c) mineral-associated organic carbon with soil depth in the various study sites.

particulate organic carbon is an accurate soil quality indicator despite soil differences, and therefore advocated that it should be considered when assessing the quality of different soil management practices.

In a study conducted by Chan (1997) and supported by Janzen et al. (1998) they pointed out that soil organic matter constituents ranged from labile compounds that mineralize during the first stage of decomposition to more resistant (mineral-associated soil organic carbon). They concluded that soil organic matter changes occur primarily in the labile fractions.

Changes in total, particulate and mineral-associated soil organic carbon with depth under the various land use management

The content of total, particulate and mineral-associated soil organic carbon was significantly influenced by soil depth (Figure 2). All the different land use types showed highest accumulation of the various carbon fractions in the surface layer (0 to 15 cm). This high level of organic carbon stock in the surface layer could be due to the slow of mixing of the soil and the litter layer formed as a result of leaf-fall from the trees.

In a 12-year experiment, Bayer et al. (2000) found that by the third year, the increase in carbon and nitrogen stocks were minimal and occurred only in the 2.5 cm top layer, however, by the 5th year, this effect had spread to the 7.5 cm depth. In the 9th and 11th year, carbon and nitrogen stocks increased through to 12.5 and 17.5 cm depths respectively. Soil organic carbon storage in deeper soil layer has been related to the development of roots systems (Pillon, 2000) and to the amount of above ground biomass addition on the soil surface (Burle et al., 2005) implying that the trees will normally improve in their respective organic carbon addition potentials, depending on the length of time and fallow period since the biomass increase with age. The organic carbon fractions were observed to decrease with depth. The top layer recorded the highest concentration of these fractions.

Conclusions

Land use management and soil depth influence contents of total, particulate and mineral-associated soil organic carbon fractions. Crop cultivation led to a decrease in total soil organic carbon, but the value was higher than the contents obtained in the fallow land. The values obtained for the contents of mineral-associated soil organic fraction were relatively higher than the particulate organic carbon pool in all land use management systems. This indicates that high proportion of total soil organic carbon composed of mineral-associated soil organic carbon. From the results it was noted that, natural forest had capacity for increasing soil organic carbon to an appreciable concentration. Fallow contribution to soil organic carbon was small. This could be attributed to several factors such as wind erosion, grazing, bush burning and cutting of vegetation for fuel wood.

The contents of total, particulate and mineral-associated soil organic carbon was significantly influenced soil depth. All the different land use types showed highest accumulation of the various carbon fractions in the surface layer (0 to 15 cm). This high level of organic carbon stock in the surface layer could be due to the slow of mixing of the soil.

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