

INFLUENCE OF SOIL PHOSPHORUS DYNAMICS ON SOIL CARBON SEQUESTRATION IN FOUR LAND USE TYPES IN ABAKALIKI, EBONYI STATE, SOUTH EASTERN NIGERIA.

Abstract

Information on soil phosphorus dynamics and its influence on soil carbon sequestration in different land use types is scanty. A research was conducted to determine the influence of soil phosphorus on soil organic carbon sequestration in four land use types in Abakaliki, south eastern Nigeria. The four land use types selected include managed forest plantation, fallow land, grass land and continuously cultivated soil. Soil samples were randomly collected from each of the land use types seasonally; two times in rainy season and two times in dry season annually at three months interval respectively for two years (described as Dry season 1, 2, 3 and 4 and Rainy season 1, 2, 3 and 4 for the period of the study 2022 and 2023). Undisturbed soil samples were collected at three soil depths (0 – 20 cm, 20 – 40 cm and 40 – 60 cm) in the selected land use types and replicated five times for bulk density determination. Auger soil samples were collected for soil chemical analysis such as soil organic carbon and available phosphorus using standard methods as follows: soil organic carbon content of the soil and aggregate –associated carbon was quantified by Walkley and Black wet oxidation method as described by Nelson and Sommers (1982) while available phosphorus was determined using Bray II bicarbonate extraction method (Bray and Kurtz, 1945) using 0.03N ammonium fluoride with 0.1NHCl. The phosphorus in the extract was determined with a photo-electric colorimeter (Udo *et al.*, 2009). On the average, soil bulk density values obtained were lowest (1.54 gcm³) in the fallow land and highest (1.71 gcm³) in the continuously cultivated soil for both seasons and for the two years. On the average, managed Gmelina plantation (MP) recorded the highest soil organic carbon (SOC) (15.45 and 23.70 gkg⁻¹ for dry and rainy seasons respectively) and mean available phosphorus (AP) (8.03 and 12.37 mgkg⁻¹ for dry and rainy season respectively) while continuously cultivated soil (CCS) had the lowest values (9.03 and 8.88 gkg⁻¹ for dry and rainy seasons respectively) and (0.93 and 0.95 gkg⁻¹ for dry and rainy season respectively) for the soil nutrients in both seasons. The result on total organic C storage showed that continuously cultivated soil (CCS) had highest value (160.17 Mg C ha⁻¹) and lowest (116.84 Mg C ha⁻¹) in grass land (GL) in dry season year 1 while in rainy season year 1 managed Gmelina plantation recorded the highest (365.51 Mg C ha⁻¹) and GL recorded the lowest (135.63 Mg C ha⁻¹). Similarly, MP recorded the highest value (340.67 and 372.06 Mg C ha⁻¹) while continuously cultivated soil (CCS) recorded the lowest value (151.49 and 220.42 Mg C ha⁻¹) for dry and rainy seasons respectively in second year. At the end of the two years study, the trend on the average total carbon storage was MF > FL > GL > CCS. The results also showed that the soil physical and chemical properties were significantly different (P < 0.05) among the four land use types and depths. It is therefore recommended that continuous cultivation without organic amendments which exposes the soil should be discouraged. Also, management practices and land use types like managed forest plantation, fallow land and grass land that increase the content of FL should be encouraged. This is because soil phosphorus encourages carbon sequestration that helps to mitigate the effect of climate change.

Key words: organic carbon, storage, land use, soil, soil phosphorus

INTRODUCTION

The Phosphorus content of rocks from which soil is formed is commonly between 500 and 1400 $\mu\text{g P/g}$, depending on the parent rock type. Of the igneous rocks basalts are usually at the upper end of this range, while granites and most sedimentary rocks are at the lower end (Robert, 1983). Typical total P contents in soils range from 150 to 700 $\mu\text{g P/g}$ (Wild 1988). Soils from very old landmasses, such as Australia and Africa, often contain low total P contents. A reduction in the concentration of P occurs as rocks weather, probably because apatite dissolves and the P is lost, before the formation of Al and Fe oxide minerals which would adsorb the P (Richardson *et al.*, 2004). Soil phosphorus occurs almost exclusively in the form of orthophosphate with total P concentrations usually in the range of 500-800 mg/kg dry soil. Quite a substantial amount of this P is associated with organic matter and in mineral soils the proportion of organic P lies between 20 and 80 % of the total P (Wang *et al.*, 2009). From the viewpoint of plant nutrition soil P can be considered in terms of 'pools' of varying accessibility to plants. Phosphate in the soil solution is completely accessible but this makes up only a minute fraction of the total soil P. The bulk of soil P is virtually inaccessible. More than 90 % of total P is present as insoluble and fixed forms including primary phosphate minerals, humus P, insoluble phosphate of Ca, Fe and Al and P fixed by hydrous oxides and silicate minerals. This fraction can be described as non labile (Mengel and Kirkby, 2001; Fasina *et al.*, 2007; Tening *et al.*, 2013). Plants obtain their P from the soil solution in the form of H_2PO_4^- and HPO_4^{2-} , although plant uptake of HPO_4^{2-} appears to be slower than uptake of H_2PO_4^- (Wang *et al.*, 2009). The ratio of these two forms is dictated by the pH, with H_2PO_4^- dominant in acid solutions (pH < 7), and HPO_4^{2-} dominant in alkaline solutions (Bucher, 2001). It is important to note that these ions are negatively charged (anions), so the plant will need a different mechanism to take up P, than the one used for cations uptake. The element phosphorus has been known to strongly coupled with C-sequestration processes, such as plant primary production and respiration (Yan, *et al.*, 2013; Wang, 2018). Carbon (C), nitrogen (N), and phosphorus (P) are the most important limiting nutrients for C sequestration in ecosystems (Murphy, 2015, Tening *et al.*, 2013). Storage of SOC results from interactions among the dynamic ecological processes of photosynthesis, decomposition, and soil respiration. Human and industrial activities over the years have led to changes in these processes and consequently to the depletion of SOC and the exacerbation of global climate change. But these human activities also now provide an opportunity for sequestering carbon back into soil. Future warming and elevated CO_2 , patterns of past land use, and land management strategies, along with the physical heterogeneity of landscapes are expected to produce complex patterns of SOC capacity in soil. Many researchers (Smith *et al.*, 1997; Mbah and Idike, 2011; Murphy, 2015; Chokor and Egborah, 2018; Dong *et al.*, 2021) observed that addition of organic manure increases carbon content and other soil nutrients and in turn increase carbon sequestration. It is critical to estimate nutrient storage and distribution to better understand how changes in nutrient availability will influence future C sequestration (Havlin *et al.*, 2006, Klaus and Rattern, 2005; Wieder *et al.*, 2015). Natural inputs of P include atmospheric deposition and weathering of primary minerals in soil, both of which are very slow, virtually in all ecosystems (Wang *et al.*, 2018). Agroecosystem P may be maintained without additional inputs by P uptake from desorption and dissolution of adsorbed and precipitated mineral P stocks until these stocks are exhausted, and from net mineralization of soil organic P (SOP) driven by heterotrophic respiration and hence loss of SOC. However, this uptake may be too slow to maintain P required of agroecosystems so that P inputs need to be augmented by P in fertilizer or manure if agro ecosystem P is to be raised (Emmanuel *et al.*, 2018). The impact of phosphorus (P) fertilizer application on the sequestration of soil

organic carbon (C) was investigated in an acidic permanent pasture soil grazed by sheep, the increase in soil C was evident in both the C concentration (mg C kg^{-1} soil) and C stocks (Mg C ha^{-1}) to a depth of at least 60 cm, with the largest difference between fertilizer treatments occurring in the top 10 cm soil layer (Elizabeth *et al.*, 2019). (Bationo *et al.*, 2007; Xiaoyan *et al.*, 2009)

According to their results, Ibrahim and Alexandra (2020) observed that P fertilizer did not have a direct impact on the SOC of the summer-maize growing season and had a positive impact on SOC during the winter-wheat growing season. P fertilization levels have positive impact on atmospheric CO_2 capture and increased SOC content (Han *et al.*, 2005). Plant nitrogen (N) and phosphorus (P) content regulate productivity and carbon (C) sequestration in terrestrial ecosystems. Estimates of the allocation of N and P content in plant tissues and the relationship between nutrient content and photosynthetic capacity are critical to predicting future ecosystem C sequestration under global change. The objective of this work, therefore, is to study the influence of phosphorus dynamics on carbon sequestration in four land use types in Abakaliki south eastern Nigeria.

MATERIALS AND METHODS

Site description

The study was carried out at four locations with a particular land use type situated in Abakaliki Ebonyi State, South Eastern Nigeria in 2020 and 2021 cropping seasons. Abakaliki in Ebonyi State lies between Latitude $06^\circ 25' \text{N}$ and longitude $08^\circ 31' \text{E}$ and altitude of 170 m. The Climate of Abakaliki area has two marked seasons; the dry and rainy seasons. The area experiences bimodal pattern of rainfall usually spread from April-July and September- October with a dry spell in August. The rainfall ranges from 1700 to 2000mm with mean annual rainfall of 1800mm (ODNRI, 1989 ; Anyadike 2002). The dry seasons begins in November and ends in April. The mean annual temperature ranges from 27°C to 31°C throughout the year. The relative humidity is high 80% during rainy season but declines to 65% in the dry season (ODNRI, 1989). The relief of the area is generally undulating and no location exceeds 200m above sea level (Ofomata, 1975). The predominant shale has favoured the erodibility of the area resulting in absence of deep cut valleys and erosion channel. Geologically, the soil of the area is underlain by sedimentary rocks derived from successive marine deposits. According to FDALR (1985), Abakaliki agricultural zone lies within Asu River and is associated with brown olive shales, fine grained sandstone and mudstone. The soils of the area being basically clayey loam underlain with laterite are particularly suitable for the cultivation of rice (*Oryza sativa*), yam (*Dioscorea spp.*), cassava (*Manihot esculenta*), maize (*Zea mays L.*) etc. The soil is shallow with unconsolidated parent material up to 1m depth belonging to the order Ultisol classified as Typic Haplustult (FDALR, 1985). The major vegetation of the area is derived savanna characterized by growth of shrubs, herbs, dispersed large trees and common tropical grasses (Anyadike, 2002). The following land uses are common in the area; shifting cultivation or bush fallow, continuous cultivation (rice farming, groundnut farming, maize farming etc.) grazing land, mixed cropping (yam/cassava/vegetable or yam/cassava/maize etc.), forest land, grass land, uncultivated land, refuse dumpsite, sewage dumpsite, etc.

The four locations and their land use history are described below as follows;

Managed Gmelina Plantation (MP): Artificial *Gmelina arborea* was established at Azugwu Abakaliki during the colonial era for preservation of forestry resources spanning for 50 years. Other species of trees and shrubs are also found growing in the plantation. The area falls within latitude $06^\circ 19' 42'' \text{N}$ and longitude $08^\circ 74' 1'' \text{E}$ and altitude of 175m (Google map, 2019;

Mbah and Idike, 2011). Hunting and farming activities are prohibited although poaching is not completely eliminated as people still encroach in the forest for farming related activities. The land area for the study was measured 100 m x 100 m which is equivalent to 1ha.

Fallow Land (FL): The fallow is located behind All Saints Cathedral, Abakaliki near Ogoja road. It lies between latitude 06°19'17N and longitude 08°06'23E (Google map, 2019). The fallow has lasted for more than 10 years. There are different types of vegetation covering the land but among major ones are scattered trees, herbs, shrubs and grasses like guinea grass (*Panicum maximum*), wire grass (*Sporobolus pyramidalis*), goat weed (*Ageratum conyzoides*), stubborn weed (*Sidaacuta*). The land area of 100 m x 100 m equivalent to 1ha was measured for the study.

Grass Land (GL) is located at Bishop Otubelu College Abakaliki. The grass land is periodically under cut especially the area that serves as field for games, some parts of the land is used to graze animals. The grass land has existed over 20 years. The land is grown with herbs but dominated by grasses such as *Tridaxprocumbens*, giant star grass (*Imperata cylindrical*), guinea grass (*Panicum maximum*), wire grass (*Sporobolus pyramidalis*), goat weed (*Ageratum conyzoides*), stubborn weed (*Sidaacuta*). The area lies between 06°19'13N longitude 08°06'19E (Google map, 2019). The land area for the purpose of the study is measured 100m x 100m equivalent to 1ha

Continuously Cultivated Soil (CCS) otherwise known as arable land is located behind Law Faculty of Ebonyi State University Abakaliki. The land is the experimental farm of the Department of Soil Science and Environmental Management, Faculty of Agriculture, Ebonyi State University, Abakaliki. The area has been under yearly cultivation for more than 20 years by students and staff of the Department. It has been subjected to conventional tillage operations, use of chemicals (like fertilizers, herbicides and pesticides), organic amendments and other cultural practices. Common crops grown in rotation include yam (*Dioscorea spp.*), Cassava (*Manihot spp.*), Maize (*Zea mays L.*), vegetables, cucumber and leguminous crops. The area lies between latitude 06°19'15N and Longitude 08°07'46E (Google map, 2019; Nwiteet *et al.*, 2018). The land area measured out for the purpose of the research is 100 m x 100 m equivalent to 1ha. The selection of the four land use types above is to have better representation of the various land use practice in Abakaliki South Eastern Nigeria.

Available Phosphorus was determined using Bray II bicarbonate extraction method (Bray and Kurtz, 1945) using 0.03N ammonium fluoride with 0.1NHCl. The phosphorus in the extract was determined with a photo-electric colorimeter (Udo *et al.*, 2009).

Soil organic carbon content of the soil and aggregate-associated carbon was quantified by Walkley and Black wet oxidation method as described by Nelson and Sommers (1982)

Soil carbon stock/pool (Mg/ha) was quantified as the product of fractional mass of carbon, soil depth (m), soil bulk density (mg/m³) and land area/ha (m²/ha) thus.

$MgC\ ha^{-1} = [\% C \times BD \times d \times 10^4 m^2] / 100$ (Lal *et al.*, 1998; Anikwe, 2010; Elizabeth *et al.*, 2019)

Where $MgC\ ha^{-1}$ = mega gram carbon per hectare (1 Mg = 10⁶g)

% C = percentage of carbon given by laboratory result

Bd = Soil bulk density (gcm⁻³)

d = depth in meters..

Bulk density was determined using core sampling method after oven drying the soil samples to a constant weight at temperature of 105°C for 24 hrs ((Blake and Hartage, 1986; Grossman and Reinsch, 2002).

Soil sampling

The land area (1 ha) for each land use type was sub-divided into eight (8) units for easy sample collection at three months interval for both dry and rainy seasons throughout the two years period of the study to determine the soil available phosphorus dynamics-. Soil samples were randomly collected from the eight sub units in each of the land use types seasonally; two times in rainy season and two times in dry season at three months interval respectively (described as Dry season 1, 2,3 and 4 and Rainy season 1, 2,3 and 4 for the period of the study). Three sampling depths (0-20cm, 20- 40cm and 40-60cm) were used for collection of two core samples each and an auger sample each from each depth of the four land use types and replicated three times using a hand pushed stainless auger (push probe, 23mm diameter) for the determination of soil organic carbon, available phosphorus and bulk density throughout the two years period of the study.

RESULTS AND DISCUSSION

1a shows the main effects of the different land use types on soil bulk density for both dry and rainy seasons. Generally, soil bulk density recorded in rainy seasons in the different land use types were higher than those recorded in dry season. In dry season, bulk density values varied from 1.68 – 1.74gcm⁻³ (with mean = 1.71gcm⁻³) in CCS; 1.50 – 1.58gcm⁻³ (with mean = 1.54gcm⁻³) in FL; 1.50 – 1.68gcm⁻³ (with mean = 1.60gcm⁻³) in GL while in MP the bulk density varied between 1.55 and 1.62gcm⁻³ with mean of 1.58gcm⁻³. In dry season 1, 2 and 4, CCS had the highest value (1.69,1.74 and 1.71 gcm⁻³) for bulk density among all the other land use types while FL recorded the lowest (1.58 and 1.54gcm⁻³) bulk density in 1 and 4 and GL had the lowest (1.50gcm⁻³) in dry season 2. Bulk densities in dry season were highly significant (P < 0.01) except bulk density at dry season 1. The trend of increase of bulk density among the land use types in dry season according to the mean values is as follows: CCS > GL > MP > FL (Table 10a). On the other hand, in rainy season, bulk density values ranged from 1.67 – 1.76gcm⁻³ (mean = 1.71 gcm⁻³) in CCS, 1.49 – 1.72 gcm⁻³ (mean = 1.59 gcm⁻³) in FL, 1.53 – 1.71 gcm⁻³ (mean = 1.65 gcm⁻³) while in MP the bulk density ranged from 1.55 - 1.62gcm⁻³ with mean of 1.59gcm⁻³. In rainy season 1 and 2, bulk density values were higher in CCS (1.71 and 1.76gcm⁻³) than FL, GL and MP. Fallow land recorded highest bulk density value (1.72 gcm⁻³) at rainy season 3 followed by CCS and GL with the same values (1.67gcm⁻³) at rainy season 4. Bulk density values are highly significant (P < 0.01) in rainy season 1 and 2 but not significant in dry season 3 and 4. The higher bulk densities in continuously cultivated soils (CCS) and grass land (GL) might be due to compaction resulting from a combination of factors such as tillage operation, human and animal trafficking, raindrops impacts, wetting and drying cycles in soils (Anikweet *et al.*, 2003; Osunbitan *et al.*, 2005 and Amenkhienan and Isitekhale, 2020) and lower concentration of SOC and SOM on surface layer of grass lands due to sparse vegetation (Wang *et al.*, 2001). Bulk density was significantly (P < 0.01) influenced by rainy season at rainy season 1 and 2 but at rainy season 3 and 4 bulk density showed no significant difference (Table 1a). Increased soil bulk density results from soil compaction, compressing larger pores to smaller pores thus decreasing soil porosity and infiltration rate (Brady and Weil, 2006; Chokor and Adesemuyi, 2018; Agata *et al.*, 2012). This agrees with findings of Nwite *et al.* (2018) who reported that, rain falling on soil causes slaking, mechanical disruption of aggregates and compaction. Table 1b presents the effect of depths and seasons on bulk density of soils of the different land use types. The bulk density in dry season at 0 – 20 cm depth varied from 1.55 to 1.62gcm⁻³ (mean = 1.58gcm⁻³), 1.60 to 1.61 gcm⁻³ (mean = 1.61 gcm⁻³) at 20 – 40 cm while at 40 – 60 cm bulk density varied 1.58 – 1.69 gcm⁻³ (mean = 1.64gcm⁻³). The bulk density values at various depths in dry season showed no significant difference except at dry season 3 which was significant (P < 0.05). Across the soil depths (0-20, 20-40 and 40-60 cm) in dry season, 40-60cm

depth had the highest mean (1.63gcm^{-3}) soil bulk density when compared to 0-20cm depth with the lowest mean (1.58gcm^{-3}). In the same vein, the values of bulk density in rainy season increased with depth with 40-60cm depth recording the highest mean value of 1.69gcm^{-3} relative to 0-20cm depth with the lowest mean value (1.55gcm^{-3}) (Table 1b). Generally, rainy season recorded higher values of bulk density than the dry season across the depths. Bulk density for rainy season were all significant ($P \leq 0.05$) except rainy season I which was not significant. The lower bulk density obtained for the soils of fallow land is a positive attribute in terms of soil structural development (Igwe, 2005; Brady and Weil, 2006; Chaudhari *et al.*, 2013). On the average continuously cultivated soil (CCS) had higher bulk density (1.71gcm^{-3}) followed by grass land (GL) (1.65gcm^{-3}), followed by managed *gmelina* plantation (MP) (1.59gcm^{-3}) while fallow land had the lowest bulk density (1.58gcm^{-3}) and the order of decrease in bulk density is $\text{FL} < \text{MP} < \text{GL} < \text{CCS}$ for rainy season. The interaction effect of location and depth on bulk density showed no significant difference for both seasons, this shows that there is no effect of location and depth on bulk density (Table 1 c).

Table 1a: Main Effects of Land Use Types on Bulk Density

Land Use	Dry season 1	Dry season 2	Dry season 3	Dry season 4	Rainy season 1	Rainy season 2	Rainy season 3	Rainy season 4
CSS	1.69	1.74	1.68	1.71	1.71	1.76	1.70	1.67
FL	1.58	1.52	1.50	1.54	1.52	1.49	1.72	1.62
GL	1.65	1.50	1.68	1.58	1.53	1.71	1.67	1.67
MP	1.62	1.55	1.56	1.62	1.55	1.59	1.62	1.62
F-LSD	NS	0.075**	0.075**	0.065**	0.0876**	0.073**	NS	NS

CCS = Continuously cultivated soil, FL = Fallow land, G = Grass land, MP = Managed *Gmelina* plantation

Table 1b: Bulk Density and Depth Dry and Rainy Seasons

Soil Depth	Dry season 1	Dry season 2	Dry season 3	Dry season 4	Rainy season 1	Rainy season 2	Rainy season 3	Rainy season 4
0-20	1.62	1.57	1.55	1.59	1.55	1.60	1.69	1.56
20-40	1.61	1.60	1.61	1.61	1.58	1.62	1.76	1.67
40-60	1.63	1.57	1.66	1.64	1.61	1.69	1.58	1.69
F-LSD(0.05)	NS	NS	0.065	NS	NS	0.063	0.083**	0.086

CCS = Continuously cultivated soil, FL = Fallow land, G = Grass land, MP = Managed *Gmelina* plantation

Table 1c: Interaction Between Land Use Types and Depths of the various soils.

Land Use	Soil Depth	Dry season 1	Dry season 2	Dry season 3	Dry season 4	Rainy season 1	Rainy season 2	Rainy season 3	Rainy season 4
CCS	0-20	1.76	1.74	1.68	1.69	1.67	1.75	1.62	1.56
	20-40	1.65	1.73	1.66	1.71	1.71	1.75	1.73	1.71
	40-60	1.65	1.75	1.71	1.74	1.75	1.79	1.74	1.73
FL	0-20	1.62	1.49	1.42	1.48	1.49	1.43	1.62	1.58
	20-40	1.55	1.58	1.51	1.54	1.52	1.46	1.72	1.64
	40-60	1.58	1.48	1.57	1.62	1.55	1.58	1.81	1.65
GL	0-20	1.69	1.51	1.60	1.56	1.51	1.67	1.57	1.62
	20-40	1.63	1.52	1.70	1.61	1.52	1.68	1.67	1.68
	40-60	1.64	1.47	1.74	1.59	1.56	1.77	1.76	1.71
MP	0-20	1.58	1.53	1.50	1.63	1.53	1.56	1.52	1.55
	20-40	1.62	1.56	1.58	1.59	1.56	1.59	1.63	1.65
	40-60	1.65	1.57	1.61	1.63	1.58	1.64	1.72	1.66
F-LSD(0.05)		NS	NS	NS	NS	NS	NS	NS	NS

DrySeason =November–April(6months) , RainySeason= May- October (6months)CCS = Continuously cultivated soil, FL = Fallow land, G = Grass land, MP = Managed Gmelina plantation

Influence of Land use types, soil depth and seasons on available Phosphorus

The effect of different land use types for both seasons on available phosphorus of the studied soils are presented in Tables 2a, b and c. It was generally observed that soil available P recorded higher values in rainy season than in dry season for all the soils under different land use types. Available P varied significantly ($P \leq 0.05$) across the land use types for all the periods of both seasons except at dry season 3. The results showed that available phosphorus obtained ranged from 3.43 to 7.10mgkg⁻¹, 4.45 to 10.71mgkg⁻¹, 3.21 to 9.28mgkg⁻¹ and 6.10 to 10.10mgkg⁻¹ for CCS, FL, GL and MP respectively for dry season. For the rainy season, soil available P varied from 6.20 to 10.57mgkg⁻¹, 11.57 to 12.9mgkg⁻¹, 7.18 to 11.29mgkg⁻¹ and 9.03 to 14.59mgkg⁻¹ for CSS, MP, GL and FL respectively. The mean values for the periods of dry season ranged between 5.55mgkg⁻¹ and 8.03 mgkg⁻¹ while the mean values for rainy season ranged between 7.42mgkg⁻¹ and 12.37mgkg⁻¹ across the land use types. Managed Gmelina plantation had the highest mean value (8.03mgkg⁻¹) for available phosphorus whereas continuously cultivated soil recorded the lowest mean values (5.55mgkg⁻¹) during the dry season. Also, Managed Gmelina plantation obtained the highest mean value (12.37mgkg⁻¹) whereas continuously cultivated soil (CCS) recorded the lowest (7.42mgkg⁻¹) for available phosphorus during the periods of rainy season. The order of increase across the land use types of available P is MP > FL > GL > CCS and MP > FL > GL > CCS.

The effect of soil depth on available P showed significant ($P \leq 0.05$) variation with soil depths in both seasons (Table 2b). Available P was observed to decrease in concentration with increase in depth as 0-20cm recorded higher values than 20-40cm and 40-60cm across the land use types for both periods except in dry season I. The mean values of available P across the depths include

8.43, 6.60 and 5.77 and 13.35, 8.69 and 7.63mgkg⁻¹for 0-20cm, 20-40cm and 40-60cm respectively for dry and rainy seasons respectively. Available P was observed to be higher in rainy season when compared with dry season. The values of available P observed in both seasons were rated low to high as they were below or slightly above 7 to 20 mgkg⁻¹ critical value recommended for most commonly cultivated crops (Adeoye and Agboola, 1985, Uponi and Adeoye, 2000; Adnouyiet *al.*, 2002, Obiagbesan, 2009, Kayode *et al.*,2018). It was observed that available P values for rainy season were moderate as they were slightly above the critical limit of 7mgkg⁻¹(Enwezoret *al.*, 1989).The interaction effect of land use types (location) and soil depths throughout the periods of dry and rainy seasons was significant for available P (Table 2c).

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Table 2a: Main effect of land use types on soil available phosphorus

Land Use	Dry Season 1	Dry Season 2	Dry Season 3	Dry Season 4	Mean	Rainy Season 1	Rainy Season 2	Rainy Season 3	Rainy Season 4	Mean
CSS	3.43	4.66	6.99	7.10	5.55	6.20	10.57	6.45	6.45	7.42
FL	4.45	5.62	9.26	10.71	7.51	11.68	14.59	9.03	9.37	11.17
GL	3.21	5.43	9.14	9.28	6.77	8.35	11.29	7.18	7.38	8.55
MF	6.10	6.13	9.77	10.10	8.03	12.26	12.92	12.73	11.57	12.37
F-LSD(0.05)	0.468**	0.648**	NS	1.543**		2.742**	1.492**	1.591**	2.269**	

Table 2b: Main effect of depths on soil available phosphorus

Soil Depth	Dry season 1	Dry season 2	Dry season 3	Dry season 4	Mean	Rainy season 1	Rainy season 2	Rainy season 3	Rainy season 4	Mean
0-20	5.58	6.31	10.40	11.43	8.43	12.91	17.16	11.85	11.49	13.35
20-40	3.21	5.62	8.68	8.90	6.60	8.61	10.37	7.96	7.80	8.69
40-60	3.78	4.44	7.29	7.57	5.77	7.35	9.49	6.73	6.94	7.63
F-LSD(0.05)	0.405**	0.562**	1.869	1.336**		2.374**	1.292**	1.378**	1.965**	

Table 2c: Interaction effect between soil depths and land use types on soil available phosphorus

Land Use	Soil Depth	Dry season 1	Dry season 2	Dry season 3	Dry season 4	Rainy season 1	Rainy season 2	Rainy season 3	Rainy season 4
CCS	0-20	5.60	5.20	7.66	7.76	5.48	12.50	7.78	7.76
	20-40	2.80	4.87	6.61	6.75	6.35	9.97	6.12	6.20
	40-60	1.88	3.91	6.69	6.79	6.67	9.23	5.45	5.39
FL	0-20	6.56	6.72	11.14	14.27	16.83	18.82	19.20	16.77
	20-40	3.93	5.53	8.77	9.46	10.96	10.32	10.72	9.66
	40-60	2.85	4.60	7.87	8.40	9.03	9.63	8.26	8.28
GL	0-20	4.64	5.46	12.43	12.62	12.30	15.96	9.15	9.44
	20-40	2.67	6.50	9.19	9.40	7.88	9.37	6.56	6.80
	40-60	2.33	4.33	5.81	5.83	4.88	8.55	5.84	5.90
MF	0-20	6.72	7.87	10.37	11.05	17.04	21.38	11.26	11.99
	20-40	3.52	5.60	10.14	10.00	9.27	11.85	8.45	8.53
	40-60	8.05	4.93	8.79	9.24	8.73	10.55	7.38	8.17
F-LSD(0.05)		0.811**	1.123	NS	2.672	NS	2.583	2.756	NS

CCS = Continuously cultivated soil, FL = Fallow land, GL = Grass land, MP = Managed Gmelina plantation.

Influence of Land use types, soil depths and seasons on Soil Organic Carbon (SOC)

The main effects of land use types, seasons and depth on soil organic carbon (SOC) is presented in Tables 3a, b and c. Soil organic carbon at dry season varied from 4.70 to 13.50gkg⁻¹ (mean = 9.03 gkg⁻¹), 6.40 to 17.50gkg⁻¹ (mean = 11.98 gkg⁻¹), 3.10 to 15.20gkg⁻¹ (mean = 10.80 gkg⁻¹) and 7.40 to 24.00gkg⁻¹(mean =15.45 gkg⁻¹) for CSS, FL, GL and MP respectively. Dry season I recorded lower values (CCS = 4.70; FL = 6.40; GL = 3.10; and 7.40gkg⁻¹) whereas dry season 4 recorded higher values (CCS = 9.32; FL = 17.50; GL = 15.20; and 24.00gkg⁻¹) compared to the other dry season periods. Soil organic carbon varied significantly among the locations (land use types) (P <0.05) at dry season. Organic carbon in all the dry season had highly significant difference (P < 0.01) except dry season 2 that had significant difference (P < 0.05).

During the rainy season, soil organic carbon (SOC) varied significantly (P <0.05) among the land use types. SOC varied significantly from 6.51 to 14.30gkg⁻¹ (mean = 8.88gkg⁻¹), 12.60 to 25.00gkg⁻¹ (mean = 17.00 gkg⁻¹), 8.60 to 17.31gkg⁻¹(mean = 12.18gkg⁻¹) and 18.10 to 30.30 gkg⁻¹ (mean = 23.70gkg⁻¹) for CCS, FL, GL and MP respectively across the periods in rainy season. The highest value of 24.00gkg⁻¹ (dry season) and 30.30gkg⁻¹(rainy season) for SOC were recorded by MP when compared with other land use types and the seasons with lowest value of 3.10gkg⁻¹(dry season) and 6.51gkg⁻¹(rainy season) were recorded by GL and CCS respectively. Generally, rainy season recorded higher values of soil organic carbon than dry season. The highest mean values of 15.45gkg⁻¹ and 23.70gkg⁻¹ for SOC in dry and rainy seasons was respectively noted in managed Gmelina plantation whereas the lowest mean values of 9.03gkg⁻¹ and 8.88gkg⁻¹ for dry and rainy seasons were from continuously cultivated soil (CCS). This might be attributed to high content of soil organic matter (SOM) in the MP soils which accords to the findings by Mbah and Idike (2011), Kirkby *et al.* (2011); Obalume *et al.* (2017); Shittu *et al.* (2018) and Orji *et al.* (2023). The trend in increase of SOC across the land use types using the mean values is MP>FL>GL> CCS for dry season within the period of the study and the same trend goes for rainy season.

Soil organic carbon (SOC) was significantly affected by soil depth (P ≤0.05) in both seasons throughout the period of study. Soil organic carbon at 0-20 cm soil depth ranged between 7.90 and 30.90 gkg⁻¹ (mean = 19.95gkg⁻¹); 3.51 – 11.70gkg⁻¹ (mean = 9.30 gkg⁻¹) at 20 – 40 cm while at 40 – 60 cm SOC values ranged from 4.80 to 7.00 gkg⁻¹ (mean = 6.18gkg⁻¹) in dry season. Soil organic carbon (SOC) mean values were higher at 0-20cm (19.95 and 26.70 gkg⁻¹ for dry season and rainy season) and lowest at 40 – 60 cm (6.18 and 8.78gkg⁻¹) depicting decrease with depths (20 – 40cm and 40 – 60 cm) for both seasons. The values for SOC across the depths ranged from 7.90 to 30.90 gkg⁻¹ at 0-20cm, 3.51 to 11.70gkg⁻¹ at 20-40cm and 4.80 to 7.00gkg⁻¹ at 40-60cm during dry season whereas for rainy season SOC ranged from 18.10 to 35.90gkg⁻¹ at 0-20cm 9.52 to 12.80gkg⁻¹ at 20-40cm and 7.40 to 10.42gkg⁻¹ at 40-60cm throughout the rainy season (Table 3b). Soil organic carbon values were higher at 0 – 20 cm depth compared to other depths. This agrees with the report of Igwe (2005) that SOC concentration occurred highest on the 0 – 20cm soil depth. The trend in depth for SOC in both dry and rainy season was 0 – 20cm >20 – 40cm > 40 – 60cm. Generally, SOC recorded higher values in rainy season than in dry season across the depths which may be due to higher moisture content of the soil during rainy season that ease the mineralization of organic materials. The mean values for SOC ranged from 6.18 to 19.95gkg⁻¹ across the depths in dry season and ranged from 8.78 to 26.70gkg⁻¹ across the depths in rainy season. A significant effect (P ≤0.05) was observed for the interaction of location (land use type) and soil depth for SOC for both seasons

(Table 3c) This shows that the interaction between the land use type is positive and would encourage carbon storage.

Table 3a: Main effects of land use types on soil organic carbon (gkg⁻¹)

Land Use	Dry season 1	Dry season 2	Dry season 3	Dry season 4	Mean	Rainy season 1	Rainy season 2	Rainy season 3	Rainy season 4	Mean
CSS	4.70	13.50	8.60	9.32	9.03	7.50	14.30	7.20	6.51	8.88
FL	6.40	9.20	14.80	17.50	11.98	25.00	17.10	12.60	13.30	17.00
GL	3.10	10.70	14.21	15.20	10.80	13.30	17.31	8.60	9.50	12.18
MF	7.40	7.81	22.60	24.00	15.45	22.10	30.30	18.10	24.30	23.70
F-LSD(0.05)	0.540**	3.470	5.390**	5.900**		0.896	0.283**	0.331**	0.291**	

Table 3b: Main effect of depths on soil organic carbon (gkg⁻¹)

Soil Depth	Dry season 1	Dry season 2	Dry season 3	Dry season 4	Mean	Rainy season 1	Rainy season 2	Rainy season 3	Rainy season 4	Mean
0-20	7.90	13.11	27.90	30.90	19.95	30.20	35.90	18.10	22.60	26.70
20-40	3.51	11.30	10.70	11.70	9.30	11.50	12.80	9.61	9.52	10.86
40-60	4.80	6.40	6.52	7.00	6.18	9.20	10.42	7.40	8.10	8.78
F-LSD(0.05)	0.470**	3.010**	4.670**	0.511**		0.776**	0.245**	0.286**	0.252**	

Dry season = November – April (6months) Rainy season = May – October (6months)

CCS = Continuously cultivated soil, FL = Fallow land, G = Grass land, MP = Managed Gmelina plantation

Table 3c: Interaction between depths and land use on soil organic carbon (gkg⁻¹)

Land Use	Soil Depth	Dry season 1	Dry season 2	Dry season 3	Dry season 4	Rainy season 1	Rainy season.2	Rainy season 3	Rainy season 4
CCS	0-20	6.60	17.30	12.10	13.00	7.30	17.91	7.60	6.50
	20-40	5.71	17.30	6.70	7.20	7.50	12.60	7.80	6.81
	40-60	4.80	5.90	6.90	7.60	7.71	12.30	6.10	6.20
FL	0-20	11.40	14.40	29.1	36.30	44.70	33.40	25.40	25.80
	20-40	2.40	9.00	8.0	8.90	14.80	10.40	7.70	8.90
	40-60	5.50	4.11	7.20	7.50	14.60	7.40	4.60	5.20
GL	0-20	3.30	15.30	30.80	33.20	22.10	32.62	16.30	18.30
	20-40	1.21	91.0	7.81	8.20	11.82	10.80	5.50	6.10
	40-60	4.70	7.60	4.10	4.40	6.00	8.50	3.90	4.00
MP	0-20	10.30	5.41	33.91	41.21	45.70	59.70	23.30	39.80
	20-40	7.11	9.70	20.30	22.40	12.00	17.60	17.30	16.20
	40-60	4.70	8.20	7.70	8.40	8.70	13.50	14.80	16.80
F-LSD(0.05)		0.930**	0.602	0.934	1.022	1.552	0.490**	0.573**	0.505**

Dry season: November –April Rainy Season : May-October, CCS = Continuously cultivated soil, FL = Fallow land, G = Grass land, MP = Managed Gmelina plantation.

Carbon Storage on Soils of the four Land use types across the three soil depths during Dry and Rainy seasons.

The quantity of carbon stored on the soils of different land use types during dry season across the soil depths is presented in Table 4 a and b.

Dry season 1 carbon storage: During the dry season 1, total organic carbon (TOC) stored varied between 10.59 and 34.34 MgCha⁻¹ with CV of 43% at 0-20cm, 7.82 and 37.55 MgCha⁻¹ with CV of 61% at 20-40cm depth, and 17.82 and 70.39 MgCha⁻¹ with CV of 43% at 40- 60cm soil depth. The mean values of carbon stored across the depths ranged from 22.73 to 46.82 with 40-60cm depth recording the highest mean value 22.73 to 46.82 with 40-60cm depth recording the highest mean value (46.82) and 20-40cm recording the lowest (22.73). Managed Gmelina plantation (MP) had the highest value for total carbon stored (133.56 MgCha⁻¹) while grass land (GL) recorded the least total (65.05 Mg C ha⁻¹) during the dry season I. The coefficient of variation during dry season I ranged from moderate to high corresponding from 43.3 to 60.6%.

Dry Season 2 carbon storage: The result of carbon storage at dry season 2 showed that carbon storage varied from 16.65 to 60.31 Mg C ha⁻¹ (mean = 41.46; CV% = 44.0%) at 0-20cm depth, 54.90 - 119Mg C ha⁻¹ (mean = 72.73; CV% = 43.5%) at 20-40cm depth and 36.03 to 77.55Mg C ha⁻¹ (mean = 60.58; CV = 29.1%) at 40 – 60 cm. The coefficient of variation was moderate according to Aweto (1980). Across the land use types, continuously cultivated soil (CCS) recorded the highest value of 241.94Mg C ha⁻¹ for carbon storage while fallow land (FL) recorded the lowest (133.84Mg C ha⁻¹) during dry season 2. Total carbon storage during dry season follows the trend CCS > GL> MP> FL. Generally, carbon storage at dry season 2 was observed to be higher than dry season I across the land use types and depths. Total carbon storage at dry season 2 was 699.11Mg C ha⁻¹ with mean value of 174.78 while that of dry season I was 378.59Mg C ha⁻¹ with mean values of 94.65. This is to say that storage of carbon is progressive during the dry season period and that there is increase in soil organic carbon accumulation across the land use types.

Dry season 3 carbon storage – The result of carbon storage in dry season 3 showed that carbon storage ranged from 40.62 - 119.55 Mg C ha⁻¹ (mean = 85.33; CV% = 39.2%) at 0-20cm; 45.22 - 128.61 Mg C ha⁻¹ (mean = 68.94; CV% = 58.0%) at 20-40cm depth while at 40-60cm the values ranged between 42.90 and 74.48 Mg C ha⁻¹ (mean = 64.07; CV% = 22%). The result of total carbon stored showed that managed forest (MF) recorded the highest value (119Mg C ha⁻¹) whereas continuously cultivated soil recorded the lowest value (40.62 Mg C ha⁻¹) at 0 – 20 cm soil depth. Across the depths MP consistently recorded the highest value. The mean value ranged from 64.07 to 85.33 and decreased with depth with this trend 0-20cm >20-40cm >40-60cm. The coefficient of variation across the depths ranged from medium to high according to Aweto (1980). This shows that storage of carbon differs from depth to depth.

Dry season 4 carbon storage – The result of carbon storage within this period showed that total organic carbon stored ranged from 17.94 to 134Mg C ha⁻¹ with CV of 56% at 0-20cm, 49.59 to 142.34 Mg C ha⁻¹ with CV of 61% at 20-40cm soil depth and 42.17 to 82 Mg C ha⁻¹ with CV of 27% at 40-60cm. The result further observed that MF consistently maintained the highest values (134.21; 142.34 and 85.15 Mg C ha⁻¹) across the depths. The mean values ranged from 68.91 to 90.77 decreased with increased depth. The coefficient of variation according to the result ranged from moderate to high across the depths. This is in line with the ranking of Aweto (1980).

The quantity of carbon stored on the soils of different land use types during rainy season across the soil depths is presented in Tables 4 a and b

Rainy season I carbon storage: The result of rainy season I carbon storage is presented in Table 4 a and b. The result showed that total carbon stored in rainy season I ranged from 24.25 to 139.99 MgC ha⁻¹ (mean 74.48; CV% = 49.0%) at 0 – 20cm depth; 36.81 to 74.57Mg C ha⁻¹ (mean = 54.36; CV% = 46.0%) at 20-40 cm while at 40-60cm soil depth the value ranged from 41.39 to 82.29Mg C ha⁻¹. The mean value across the depths ranged from 54.36 to 74.48 MgC ha⁻¹ with 0-20cm recording the highest (74.48 Mg C ha⁻¹) and 20 – 40 cm recording the lowest (54.36Mg C ha⁻¹). The result of carbon storage further showed that managed Gmelina plantation (MP) recorded the highest value (139.99Mg C ha⁻¹) for carbon stored at 0 – 20cm soil depth while continuously cultivated soil (CCS) land use type had the lowest (24.56 Mg C ha⁻¹) and the trend followed by the total carbon storage is MP>FL>GL>CCS (Table 3a). The coefficient of variation varied from low to high across the period based on the scale by Aweto (1980).

Rainy season 2 carbon storage: The result of carbon storage at 0-20cm, 20-40 cm and 40-60 cm varied from 20.19 to 186.23 Mg C ha⁻¹ with CV of 60.0%, 40.92 to 112.06Mg C ha⁻¹ with CV of 46.0% and 41.66 to 135.88 Mg C ha⁻¹ with CV of 69.0% respectively. The average value across the depths varied from 64.31 to 86.80Mg C ha⁻¹ with 0-20 cm recording the highest mean value (86.80Mg C ha⁻¹) and 20 – 40 cm recording the lowest mean value (64.31Mg C ha⁻¹), (Table 4a). Managed Gmelina plantation (MP) land use type recorded the highest total carbon stored (186.23 Mg C ha⁻¹) while continuously cultivated soil (CCS) land use type recorded the lowest (20.19 Mg C ha⁻¹) at 0 – 20 cm soil depth.

Rainy season 3 carbon storage: The result of carbon storage in rainy season 3 showed that carbon storage ranged from 24.56 – 136.13Mg C ha⁻¹ (mean = 79.51; CV% = 61.0%) at 0 – 20 cm; 36.81 to 103.08Mg C ha⁻¹ (mean = 76.13; CV = 18.3%) at 20 – 40 cm while at 40 – 60 cm, the values ranged between 56.25 and 152.63 Mg C ha⁻¹ (mean = 106.34; CV% = 38.6%). The value of carbon storage was highest (153.63 Mg C ha⁻¹) in MP at 40-60 cm depth with mean value of 106.34Mg C ha⁻¹ and lowest CCS (24.56 Mg C ha⁻¹) at 0 – 20 cm soil depth. Among the land use types, FL recorded the highest value (136.13Mg C ha⁻¹) for carbon storage at 0 – 20 cm depth while GL had the lowest value (24.56 Mg C ha⁻¹). The coefficient of variation across the depths ranged from moderate to high corresponding from 18.3 to 61.0% (Table 4b).

Rainy season 4 carbon storage: The values of carbon storage within the land use types ranged between 62.89 – 133.06 Mg C ha⁻¹ in CCS; 59.33 – 95.50 Mg C ha⁻¹ in FL; 72.97 – 108.68 in GL while in MF the values of carbon storage across the depths in rainy season 4 ranged from 106.47 – 167.63 Mg C ha⁻¹. Across the depths carbon storage varied from 62.89 to 123.29 Mg C ha⁻¹ with CV of 48.1% and mean of 97.59 at 0-20 cm depth, 59.33 to 106.47 Mg C ha⁻¹ with CV of 28.2% and mean of 81.71 at 20-40cm and 70.63 to 167.63Mg C ha⁻¹ with CV of 32.1% and 115.24 at 40-60cm soil depth. The mean values ranged from 81.71 to 115.24 Mg C ha⁻¹ with 40-60cm recording the highest average value (115.24 Mg C ha⁻¹) and lowest mean value (81.71Mg C ha⁻¹) is recorded at 20 – 40 cm. The MF like in rainy season III recorded the highest value (167.63) for carbon storage across the depths and across the various land use types especially at 40 – 60cm and the lowest is recorded by GL at the same depth (40 – 60 cm). The trend in increase of total carbon across the land use types during rainy season is MF >FL>GL>CCS. The coefficient of variation across the depths ranged from low to moderate reflecting 28.2% to 48.1% (Aweto, 1980) (Table 4b).

Comparatively, the total carbon storage at the end of the study showed that the soils of CCS, FL, GL and MF recorded 311.66, 334.79, 312.76 and 484.80Mg C ha⁻¹, respectively, during the dry season and 356.98, 473.87, 368.79 and 737.57Mg C ha⁻¹ during the rainy season (Table 5). The mean values of the carbon storage ranged from 155.83 to 242.40 and 178.49 to 368.79 for dry and rainy seasons respectively. The total carbon storage at the end of the study across the land use types for dry and rainy seasons is 1444.01MgCha⁻¹ and 1937.21Mg C ha⁻¹ respectively (Table 6). Managed Gmelina plantation (MP) had the highest value (484.80Mg C ha⁻¹ and 737.57 Mg C ha⁻¹) for total carbon storage for both seasons and continuously cultivated soil recorded the lowest (311.66 Mg C ha⁻¹ and 356.98 Mg C ha⁻¹) and the trend of increasing carbon storage for both season at the end of the study is MF > FL > GL > CCS.

The cumulative result of the two years study shows that all the land use types stored higher carbon during the rainy season (CCS =356.98 ; FL = 473.87; GL = 368.79 and MP = 737.57 Mg C ha⁻¹) than the dry season (CCS =311.66; FL = 334.79; GL = 312.76 and MP = 484.80 Mg C ha⁻¹) (Table 6) which might be attributed to high availability of carbon – storage friendly nutrient elements like nitrogen and phosphorus through soil organic matter (SOM).The result showed that carbon sequestration can be influenced positively by the presence and availability of organic carbon and phosphorus since carbon storage increased with increasing SOC and AP. This observation was also made by these researchers (Agren *et al.*, 2012; Norby *et al.*, 2010; Wieder *et al.*, 2015). The difference observed in total C stored in the soils of different land use types (Table 5) could be attributed to either the agricultural management practices, seasons or the variability in the silt + clay contents of the soils. Dai and Huang (2005) and Nottingham *et al.* (2020) observed that integrated effect of natural factors (such as rainfall, temperature and relative humidity) and human activities on soils makes the quantities of SOM and SOC maintain a steady dynamic balance in each given eco climatic zone.

The overall results at the end of the study also showed that among the land use types studied, value of carbon stored in managed Gmelina plantation (MP) was highest (1222.37 Mg C ha⁻¹) followed by Fallow land (FL) (808.66 Mg C ha⁻¹), Grass land (GL) (681.55Mg C ha⁻¹) and continuously cultivated soil (CCS) having the lowest value (668.64 Mg C ha⁻¹) (Table 6). This corresponds with Orji *et al.* (2023), Mbah and Idike (2011); Nowak and Green field (2002); and Xie and Steinberger (2001) who observed that soils of between and under trees and shrub canopies had significantly higher concentration of organic carbon, phosphorus and nitrogen and store more carbon than grassland.

Table 4 a and b: Carbon Storage on Soils of the four Land use types across the three soil depths during Dry and Rainy seasons.

Table 4 a: Dry season 1 and 2 carbon storage (Mg C ha⁻¹) (Year 1) Rainy season 1 and 2 carbon storage (Mg C ha⁻¹) (Year 1)

Dry season I				Dry season 2			Rainy season I				Rainy season 2		
Land use	0-20	20-40	40-60	0-20 cm	20-40 cm	40-60 cm	Land use	0-20cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm
CCS	23.03	37.55	17.82	60.31	119.99	61.64	CCS	24.56	53.91	64.10	20.19	46.31	64.04
FL	34.34	14.82	52.42	42.91	54.90	36.03	FL	82.20	52.15	47.47	81.50	57.96	51.48
GL	10.59	7.82	46.64	46.06	55.45	67.12	GL	51.18	36.81	41.39	59.29	40.92	41.66
MF	32.45	30.72	70.39	16.56	60.59	77.55	MF	139.99	74.57	82.29	186.23	112.06	135.88
TOTAL	100.41	90.91	177.27	165.84	290.93	242.34	TOTAL	297.93	217.44	235.25	347.21	257.25	293.06
Mean	25.10	22.73	46.82	41.46	72.73	60.58	Mean	74.48	54.36	58.81	86.80	64.31	73.27
CV(%)	43.3	61.0	43.4	44.0	43.5	29.1	CV	49.0	46.0	66.0	60.0	46.0	69.0

CCS = Continuously cultivated soil, FL = Fallow land, GL = Grass land, MF = Managed forest plantation, CV = Coefficient of variation

Table 4b Dry season 3 and 4 carbon storage (Mg C ha⁻¹) (Year 2) Rainy season 3 and 4 carbon storage (Mg C ha⁻¹) (Year 2)

Dry season 3			Dry season 4				Rainy season 3			Rainy season 4			
Land use	0-20	20-40	40-60	0-20	20-40	40-60	Land use	0-20cm	20-40cm	40-60	0-20	20-40	40-60
CCS	40.62	45.22	70.89	17.94	49.59	78.72	CCS	24.25	51.51	81.06	62.89	88.06	133.06
FL	82.70	48.62	68.01	107.39	54.82	72.61	FL	136.13	77.98	135.41	95.50	59.33	70.63
GL	98.43	53.31	42.90	103.52	51.51	42.17	GL	66.86	71.93	56.25	108.68	72.97	89.63
MP	119.55	128.61	74.48	134.21	142.34	82.15	MP	91.02	103.08	152.63	123.29	106.47	167.63
TOTAL	341.3	275.76	256.28	363.06	298.26	275.65	TOTAL	318.26	304.50	425.35	390.36	326.83	460.95
Mean	85.33	68.94	64.07	90.77	74.57	68.91	Mean	79.57	76.13	106.34	97.59	81.71	115.24
CV(%)	39.15	57.90	22.41	55.56	60.66	26.50	CV	61.0	18.3	38.6	48.1	28.2	32.1

CCS = Continuously cultivated soil, FL = Fallow land, GL = Grass land, MF = Managed forest plantation, CV = Coefficient of variation

Table 5a :AverageCarbonStorage on Soils of the four Land use types across the three soil depths during Dry and Rainy seasons(Year 1).

YEAR 1								
Land use	Dry season carbon storage (MgCha ⁻¹)				Rainy season carbon storage (MgCha ⁻¹)			
	0-20 cm	20-40 cm	40-60cm	TOTAL	0-20 cm	20-40 cm	40-60 cm	TOTAL
CCS	41.67	78.77	39.73	160.17	22.38	50.11	64.07	136.56
FL	38.63	34.86	44.23	117.71	81.85	55.06	49.48	186.38
GL	28.33	31.64	56.88	116.84	55.24	38.87	41.53	135.63
MF	24.51	45.66	73.97	144.13	163.11	93.34	109.09	365.51
TOTAL	133.13	190.92	209.81	538.85	322.58	237.38	264.17	824.08
Mean	33.28	47.73	53.7	134.72	80.65	59.35	66.04	206.02
CV(%)	44.0	52.0	46.0		55.0	48.0	70.0	

CCS = Continuously cultivated soil, FL = Fallow land, GL = Grass land, MF = Managed forest plantation, CV = Coefficient of variation

Table 5b: Average carbon storage on soils of the four land use types across the three soil depths during dry and rainy seasons

YEAR 2

Land use	Year 2 Dry season carbon storage (MgCha ⁻¹)				Year 2 Rainy season carbon storage (Mg C ha ⁻¹)			
	0-20 cm	20-40 cm	40-60cm	Total	0-20 cm	20-40 cm	40-60cm	Total
CCS	29.28	47.41	74.81	151.49	43.57	69.79	107.06	220.42
FL	95.05	51.72	70.31	217.08	115.82	68.66	103.02	287.49
GL	100.98	52.41	42.54	195.92	87.77	72.45	72.94	233.16
MF	126.88	135.48	78.32	340.67	107.21	104.78	160.13	372.06
TOTAL	352.18	287.01	265.97	905.16	354.37	315.68	443.15	1113.13
Mean	88.05	71.76	66.49	226.29	88.59	78.92	110.79	207.66
CV(%)	48.0	60.0	25.0		54.0	22.0	34.0	

CCS = Continuously cultivated soil, FL = Fallow land, GL = Grass land, MF = Managed forest plantation, CV = Coefficient of variation

Table 6: SUMMARY OF TOTAL CARBON STORAGE FOR DRY AND RAINY SEASONS FOR THE STUDY PERIOD

Land use	DRY SEASON CARBON STORAGE (Mg C ha ⁻¹)				RAINY SEASON CARBON STORAGE (Mg C ha ⁻¹)				
	1 ST YEAR	2 ND YEAR	TOTAL	MEAN	1 ST YEAR	2 ND YEAR	TOTAL	MEAN	TOTAL FOR THE 2 YEARS
CCS	160.17	151.49	311.66	155.83	136.56	220.42	356.98	178.49	668.64
FL	117.71	217.08	334.79	167.39	186.38	287.49	473.87	236.94	808.66
GL	116.84	195.92	312.76	156.38	135.63	233.16	368.79	184.39	681.55
MF	144.13	340.67	484.80	242.40	365.51	372.06	737.57	368.79	1222.37
TOTAL	538.85	905.16	1444.01	722.01	824.08	1113.13	1937.21	968.605	3381.22
Mean	134.7	226.23	361.01	180.51	206.02	278.28	484.31	242.16	845.305
CV(%)	15.7	5.8	23.1	39.9	52.9	24.9	36.5	36.5	

CCS = Continuously cultivated soil, FL = Fallow land, GL = Grass land, MF = Managed forest plantation.

Conclusion

The study of the influence of phosphorus dynamics on soil organic carbon sequestration in four selected land use types in Abakaliki showed that total nitrogen and soil organic carbon were significantly different ($P < 0.01$) among the land use types and soil depths and decreased with soil depths across the two seasons. The soil bulk densities were significantly different ($P < 0.01$) among the land use types and soil depths across the seasons and increased with depths especially in rainy season. The lowest bulk density was obtained in the fallow land (FL) whereas the highest was obtained in the continuously cultivated soil (CCS). Soil organic carbon (SOC) and available phosphorus (AP) were observed to be higher in rainy season than dry season. Managed Gmelina plantation (MF) recorded the highest values for SOC and AP for both seasons throughout the period of study when compared with the other land use types. This could be as a result of the high litter fall which has the capacity of increasing organic matter content and also due to little or no disturbance in MF.

The overall result of soil organic carbon storage was recorded higher during the rainy season than the dry season. Managed Gmelina plantation (MP) had the highest carbon storage for both seasons while continuously cultivated soil (CCS) recorded the lowest value among the land use types. This could be as a result of the availability of phosphorus in MP land use type. Therefore, since with available P, soil organic carbon storage (sequestration) is encouraged in managed Gmelina plantation and other land use types studied except continuously cultivated soil, the practice of continuously cultivation without proper application organic amendments should be discouraged as a strategy to mitigate the effect of climate change.

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