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Full Length Research Paper

Carbon accumulation and aggregate stability in an Acrisol under different fallow management in Ghana

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Soil organic carbon (SOC) in relation to aggregate stability, plant biomass accumulation and other properties of a Ferric Acrisol under different fallow management practices was determined to ascertain their potential for sequestering carbon. Three minor season fallow treatments replicated four times were natural and burning (T_1), natural and plough-in (T_2), pigeon pea (T_3), bare land (T_4), cowpea (T_5), mucuna (T_6) and natural and fertilized cropped (T_7).Inherent nutrient status of the soil was low. Generally, dry matter (DM) yield increased for all the treatments in the minor season of 2006 more than in 2005. A high DM yield for T_3 resulted from the shrubby and semi-woody nature of pigeon pea.Moisture stress from low rainfall decrease DM yield in 2007. In 2005, SOC contents of the treatment plots were lower than the initial amount although, T_3 produced relatively the highest SOC accumulation (20,293 ± 326 kg C ha^{-1}). In 2006, the legume-amended treatments (T_3, T_5 and T_6) had similar SOC contents as the control (T_4); the lower SOC contents in the natural fallow plots confirmed the negative effect of burning, especially in T_1. Soil OC accumulation was greater in 2007 than in 2006 (except for T_4). Water dispersible silt fraction decreased with increasing SOC accumulation (r value = - 0.88). Dispersion ratios, more related to SOC (R^2 value of -0.95** in the natural fallows and - 0.76* in the legume fallows), generally decreased from an average of 0.88 in 2006 to 0.50 in 2008 emphasizing the positive role of aggregate stability in SOC accumulation.**

Key words: Organic carbon, crop fallow, dispersion ratio, bulk density, dry matter yield, erodibility, plant biomass, particle size distribution.

INTRODUCTION

Land degradation through erosion and soil fertility depletion are the most serious threats to food production in Africa (Lal and Ragland, 1995; Eswaran et al., 2001; Amberger, 2006). Organic carbon levels in most soils are very low, below 10 g kg^{-1} (Jones et al., 2006) due, in part, to soil loss. Consequently, aggregation of the individual soil particles becomes very weak making the soils highly erodible. In spite of this, soils of the tropics have a large potential of serving as sinks for atmospheric carbon through addition of organic matter (IPCC, 2000; Bayer et al., 2000, 2006; Sá et al., 2001; Bernoux et al., 2006; Cerri et al., 2007). Coincidentally, concern has been mounting globally on the rapid build-up of CO_2 in the atmosphere (Pacala and Socolow, 2004; Houghton, 2007). According to IPPC (2007), annual emissions of the gas have increased between 1970 and 2004 by about 80%, from 21 to 38 gigatonnes (Gt), and represented 77% of total anthropogenic GHG emissions in 2004.This rate of increase of CO_2-eq emissions was much higher during the 10-year period of 1995 to 2004 (0.92 Gt CO_2-eq per year) than during the previous decade.

Soil organic matter is the primary reservoir of essential soil nutrients. Its addition can, therefore, form the basis for sustainable management of tropical soils. With maintenance of organic matter, productivity of tropical soils can be sustained over a long period of time. Management of tropical soils must ensure that organic residues are always returned into the soil. In tropical ecosystems, both plants and soils provide attractive

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resources for harnessing carbon. A good biomass turnover must be an integral component of cropping systems. Research on soil management system that will be economically attractive to the farmer but at the same time conserve soil organic matter has not received great attention in tropical Africa (Albrecht and Kandji, 2003; Adiku et al., 2008; Dowuona and Adjetey, 2010).Ongoing studies on some Ghanaian soils may provide the requisite information to fill this gap. Furthermore, data on traditional methods adapted by farmers to conserve soil carbon in relation to aggregate stability in the various farming systems are very scanty. It is, therefore, necessary to bridge these gaps in knowledge to provide relevant information to enhance the use of soils in the savanna and forest ecosystems of Africa. In the humid and sub-humid ecosystems of the tropics, the farming season follows the bimodal rainfall regimes. Small scale farmers constitute the larger proportion of the farming population, and they practice slash and burn rain-fed-agriculture (Sanchez, 1995; Waters, 2007). The slash and burn rain-fed agriculture has culminated in farming systems that take into account little or no build-up of organic carbon in the soil. Soils are, therefore, fragile with poor stability and prone to erosion (Eswaran et al., 1995, 2001).Thus in times of heavy tropical rains, the top soils with very little conserved nutrients are washed away. To improve on the productivity of the soils, particularly in the humid tropics, farmers are being encouraged to plant indigenous fallow crops in the minor season, when rainfall is erratic, and turning them into the soil to serve as nutrient base for the major season planting (Adiku et al., 2008). However, information on the amount of carbon sequestered in the indigenous and improved farming systems in West Africa is very scanty (Adiku et al., 2008; Takimoto et al., 2008). Additionally, the impact of this new practice on stability and erodibility of the soil vis-à-vis carbon accumulation has not yet been assessed. Dispersion ratio (DR) has been found to be a better index of measuring erosion than aggregate stability in some West African soils (Mbagwu, 1986; Obi et al., 1989; Igwe et al., 1995). However, assessment of the DR in relation to carbon accumulation in soils is very limited in West Africa. It is therefore, imperative to provide information on the impact of improved land fallow management on the erodibility of the soils for farmer's adoption and adaptation to ensure sustainable environmental management. The objective of the study was, therefore, to assess changes in the contents of carbon in a widely cultivated savanna soil under different crop-fallow management systems to provide a basis for understanding how the practice impacts on soil carbon build-up and soil aggregate stability and erodibility using dispersion ratio as an index.

MATERIALS AND METHODS

Site characteristics and field experiment

The study was conducted at a site located between latitudes 05° 39.546' and 05° 39.561' N and longitudes 000° 11.621' and 000° 11.641' W within the semi arid coastal savanna zone of Ghana (Figure 1). This zone is part of the sub-humid to semi-arid savanna zones, which are the largest ecosystems of West Africa.The study site was nearly flat in topography. Total annual rainfall was 800 mm and the average temperature was about 27°C.The coastal savanna zone had two planting seasons, a major season (April to July) and a minor season (September to November).The site which had been under fallow for ten years was colonized by grasses (*Panicum maximum* and *Pennisetum purpureum*) and herbaceous plants (*Chromolaena odorata*).The soil, classified as Ferric acrisol (WRB, 2006) is among the dominant and widely cultivated soils in the coastal savanna zone.

The land was cleared of the native vegetation in the major season of 2005 and seven plots, each of size 6 m × 5 m with four replicates (a total area of 840 m^2 exclusive of a 1 m border row between each replicate plot), were demarcated and put to maize (*Zea mays* L.) cultivation. Six of the plots under the maize cultivation received no fertilizer application (as is normally practiced by farmers) and one had fertilizer application 60 kg NPK /ha). In the major seasons of 2006 and 2007, the treatment in 2005 was repeated. In the minor seasons of 2005, 2006 and 2007 after each major season maize cultivation, the under listed completely randomized seven fallow land preparation treatments, were imposed on the plots:

T_1: plot left under natural fallow (grasses and herbaceous plants), the vegetation cut and burnt at the onset of the following major cropping season,
T_2 plot left under natural fallow (grasses and herbaceous plants), the vegetation cut and ploughed into the soil at the end of the minor season,
T_3 plot planted with pigeon pea (*Cajanus cajan*), slashed and applied as surface mulch at the end of the minor season,
T_4 plot kept free of vegetation (bare) during the minor season (i.e. control plot),
T_5 plot planted with cowpea (*Vigna unguiculata*), slashed and applied as surface mulch at the end of the minor season,
T_6 plot planted with mucuna (*Mucuna pruriens*), slashed and applied as surface mulch at the end of the minor season, and
T_7 (plot planted with maize (*Zea mays* L.) with fertilizer application in the major season) plot allowed to fallow naturally in the minor season; the vegetation slashed and surface applied at the end of the minor season.

Dry matter yield

The above ground biomass (seeds and grains of legumes excluded) of the fallow plant materials were harvested at the end of the three minor cropping seasons of 2005, 2006 and 2007.The dried weight of plant materials from each treatment plot was determined by drying in an oven at 65°C for 48 h and the dry matter (DM) yield expressed in kg ha^{-1}.

Soils and sampling

Site characterization prior to this study was undertaken in the major season of 2005 before the onset of the study for characterization to establish uniformity of the soil. This was done by series of augering to a depth of 100 cm to locate the modal profile that was representative of the soil at the study site. The modal profile was dug, described and sampled from genetic horizons and followed by laboratory analyses on selected physical and chemical properties. In addition, soil was sampled at random (in triplicate) at each of the demarcated site at the time of the site characterization in 2005 to determine carbon content before the experiment started the following year. At the beginning of the major seasons of 2006,

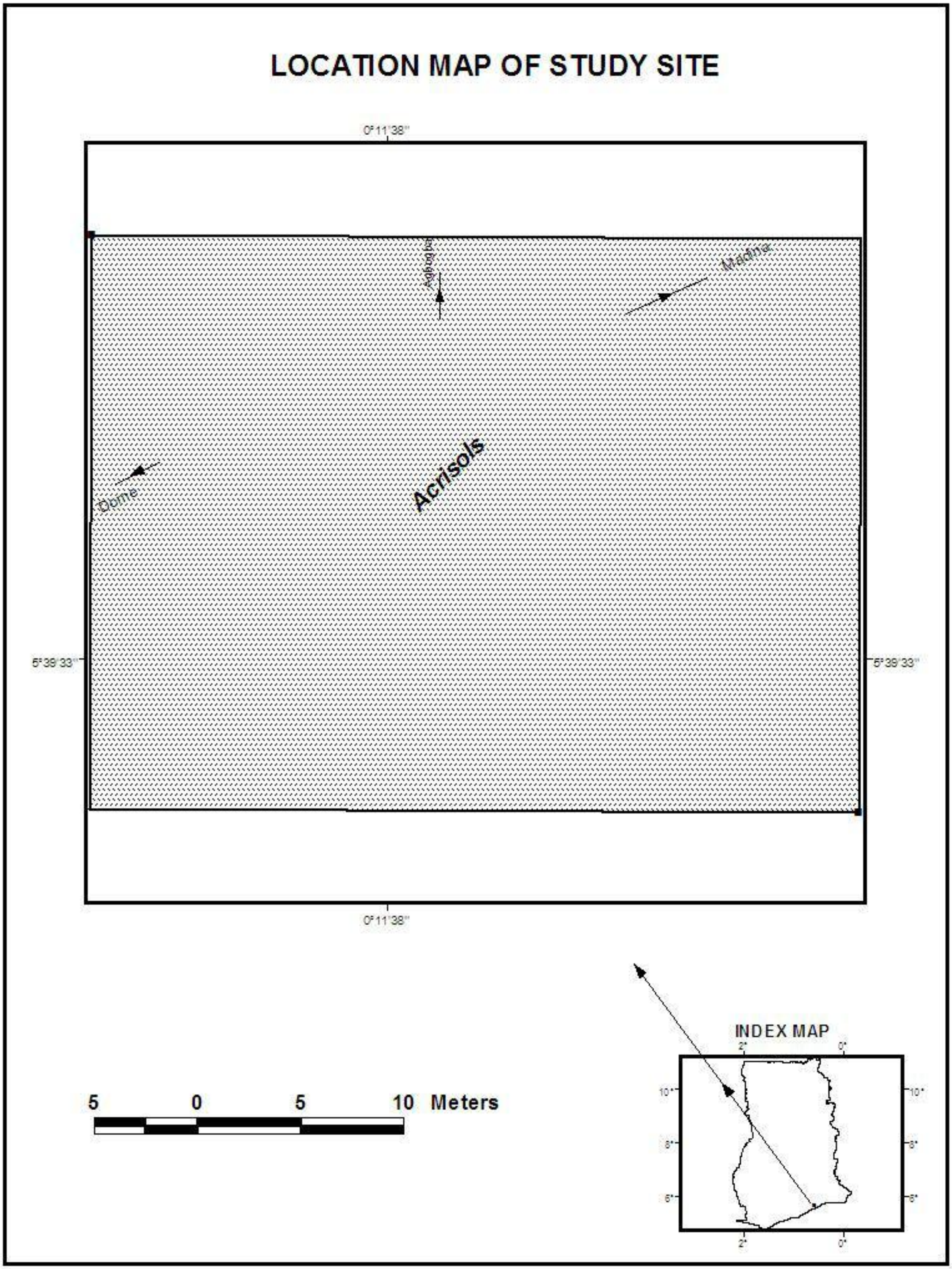

Figure 1. Location of the study site.

2007 and 2008 disturbed and undisturbed soil samples were taken from each plot at a depth of 0 to 20 cm for laboratory analyses.

Laboratory analysis

Laboratory analyses were carried out on the modal profile samples and also on the surface samples collected from the treatment plots in 2005, 2006 and 2007.For the profile samples the properties selected were pH, organic carbon, available phosphorus, total nitrogen, cation exchange capacity, bulk density and particle size distribution. Organic carbon, particle size and bulk density were determined for the surface (0 to 20 cm) samples.

Bulk density was determined on the undisturbed samples using the clod method (Blake and Hartge,1986) while particle size distribution in calgon (c) was by the modified Bouyoucos hydrometer (Day, 1965) and repeated with water dispersion (w).The dispersion ratio (DR) as an index of aggregate stability and erodibility (Middleton, 1930) was calculated as:

$$DR = (\% \text{ silt} + \% \text{ clay})_w / (\% \text{ silt} + \% \text{ clay})_c \quad (1)$$

Where 'w' is dispersion in water and 'c' is dispersion in calgon.

The pH of soil samples (1:1 soil/water) from the modal profile was determined in distilled water. Cation exchange capacity was determined by the 1 M ammonium acetate (pH 7.0) method. Total nitrogen was determined by the acid digestion Kjeldahl method (Bremner and Mulvaney, 1982). Available phosphorus was determined by the method of Bray and Kurtz (1945).Organic carbon content of the soils (0 to 20 cm) determined by the dry combustion method involving the use of the carbon analyzer (Eltra CS 500 Carbonator).The amount of organic carbon accumulated in the soil was estimated using the area-based quantitative equation of Schlesinger (1986) as:

$$\text{Organic carbon (kg/ha)} = c \times BD \times d \times 10^4 \quad (3)$$

Where c is concentration of organic carbon (g kg^{-1}), BD is bulk density (Mg m^{-3}) and d is sampling depth (that is, 0.2 m).Data obtained were statistically analyzed for mean, standard error (SE), coefficient of correlation and least square deviation (LSD) and 1% (**) and / or 5% (*) degrees of significance.

RESULTS AND DISCUSSION

General soil properties

Field examination of the modal profile confirmed uniformity of soil at the study site. The texture of the soil varied from sandy clay loam at the surface to sandy clay in the B and C horizons. The particle size distribution using calgon gave higher values of clay but lower sand and silt contents than the respective sizes using water alone as the dispersion agent. The high sand content coupled with the sandy clay loam texture is consistent with the nature of the parent material (sandstone) from which the soil formed (Brammer, 1962).Bulk density varied from 1.25 Mg m^{-3} at the in the A horizon to 1.42 Mg m^{-3} (Table 1) in the weathered parent material. The pH values fell within the range of 6.3 to 6.7 while the concentration of exchangeable bases in the soils was very low and nearly uniform with CEC less than 13 cmol(+) kg^{-1} (Table 2).Organic carbon content ranged from 8.7 g kg^{-1} in the Ap1 horizon to 1.3 g kg^{-1} in the parent material with corresponding total nitrogen content between 1.52 and 0.89 g kg^{-1}.Available phosphorus levels are very low (1.3 to 4.1 mg kg^{-1}). The analytical data confirmed the general low nutrient status of the soil noted in previous studies (Dowuona 1985).

Fallow plant biomass

The dry matter (DM) yields of the fallow plant materials at the end of 2005, 2006 and 2007 minor seasons are provided in Table 3. In 2005, the DM yield was in the order of $T_7 > T_3 = T_2 = T_6 > T_1 = T_5$.The maize cultivation started in the major season of 2005, after ten years of colonization of the site by the natural vegetation. It may have, therefore, been easy for the treatments under the natural fallow, particularly T_7, to re-establish faster and grow more luxuriantly in the ensuing minor season due to the residual nutrient boost after the three- month period of fertilized maize production in preceding major season. This could have accounted for the highest DM yield of 4,170 kg ha^{-1} in the minor season of 2005 for T_7.

With the exception of T_5 and T_7, there were general increases in DM yield in all the treatments in the minor season of 2006 compared to that in 2005.In fact, the legume fallow treatments (T_3 and T_6) had more than a two-fold increase in their respective DM yields. Treatment T_3 (pigeon pea) had strikingly, the highest biomass as compared to the others. This was likely due to its shrubby and semi-woody nature. The least DM values over the study period were recorded in 2007 which ranged from 1,464 ± 97 kg ha^{-1} in T_1 to 3,209 ± 122 kg ha^{-1} in T_6.The low DM values in 2007 could be ascribed to the poor distribution of rainfall encountered in the minor season of that year (Figure 2). In fact, there was no rain recorded in November of 2007.

The amount of DM determines the amount of litter that could be transferred into the soil when applied as mulch or burnt to release nutrients and which would improve on the stability of the aggregates. Greater dry matter addition implies higher carbon addition but the amount stored will depend on the chemical composition and the prevailing environmental conditions. On the basis of yield, one could argue that T_3 and T_6 offer the best alternative in improving DM addition to the soils.

Carbon accumulation in the soil

Quantitative data on OC accumulated in the soil after the minor season biomass additions are shown in Table 4. The mean carbon content at the onset of the experiment in the major season of 2005 was 21750 ± 398 kg ha^{-1}, which could serve as a reference base for assessing impact of the fallow treatments on carbon build up. The relatively lower carbon content in the minor season of 2005 was largely due to uptake by the major season

Table 1. Physical properties of the modal profile.

Horizon	Depth (cm)	Particle size distribution† (%)						BD‡ (Mg m^{-3})	DR‡
		$Sand_c$	$Silt_c$	$Clay_c$	$Sand_w$	$Silt_w$	$Clay_w$		
Ap1	0-6	64.8	9.4	25.8	80.0	15.4	5.6	1.25	0.57
Ap2	6-22	61.2	11.4	27.4	79.1	18.1	2.8	1.29	0.54
Bt1	22-45	58.3	8.5	33.2	78.7	18.2	3.1	1.30	0.51
Bt2	45-75	51.4	11.2	37.4	76.7	20.0	3.3	1.35	0.48
Bt3	75-120	49.3	9.9	40.8	81.2	14.7	4.1	1.40	0.37
BC	120-160	48.9	7.5	36.6	82.1	13.6	4.3	1.36	0.35
C	160-195	46.2	9.1	44.7	82.8	12.4	4.8	1.42	0.32

+C = calgon dispersion; w = water dispersion. ‡ BD = bulk density; DR =dispersion ratio.

Table 2. Chemical properties of the modal profile.

Horizon	Depth(cm)	pH†		g kg^{-1}		AP‡ (mg kg^{-1})	CEC (cmol(+) kg^{-1})
		H_2O	$CaCl_2$	OC‡	TN‡		
Ap1	0-6	6.6	5.5	8.7	1.52	4.1	10.75
Ap2	6-22	6.4	5.2	4.9	1.43	2.8	9.92
Bt1	22-45	6.3	5.1	3	1.34	2.2	9.93
Bt2	45-75	6.3	4.9	3.2	1.2	1.7	10.71
Bt3	75-120	6.2	4.8	2.2	1.24	1.5	9.42
BC	120-160	5.9	4.8	1.4	1.05	1.4	10.62
C	160-195	5.9	5	1.3	0.89	1.3	9.62

† = 1:2 (soil: solution); ‡ OC = organic carbon; TN =total nitrogen; AP = available phosphorus.

Table 3. Dry matter yield in the minor seasons.

Treatment	Dry matter yield† (kg ha^{-1})		
	2005	2006	2007
T1	2449 ± 101	2930 ± 105	1464 ± 97
T2	2954 ± 121	4279 ± 115	2762 ± 103
T3	3024 ± 104	8121 ± 169	2475 ± 101
T4	npm	npm	npm
T5	2389 ± 98	1743 ± 107	1634 ± 99
T6	2722 ± 102	5917 ± 121	3209 ± 122
T7	4170 ± 124	3239 ± 130	2833 ± 117

LSD (among years) = 238.4); LSD (among treatments) 364.7; † npm = no plant material.

maize.

In the minor season of 2005, even though plant biomass added to the soils in the plots were highest in the T_7 treatment, it did not reflect in the amount of carbon accumulated in the soil in the following major season of 2006. This is because addition of 4,170 ± 124 kg ha^{-1} of biomass did not translate into the highest level of C accumulated. It was rather the T_3 plot which after receiving 3,024 ± 104 kg ha^{-1} of DM (Table 3) that had the highest organic carbon accumulation of 20,293 ± 326 kg ha^{-1} (Table 4). It is important to note that in 2006, the three legume-amended treatments (T_3, T_5 and T_6) had statistically similar carbon accumulations as the control whereas the natural fallow amended plots had lower organic carbon accumulations in their respective soils than in the control. The T_1 was the plot that recorded lowest carbon accumulation in 2006 prior to planting.

The relatively low carbon accumulated in T_1 (15,569 ± 215 kg ha^{-1}) which was almost 3,500 kg ha^{-1} less than that in the bare soil (control) illustrates the negative effect of burning as noted elsewhere in the tropics (Eswaran et al., 2001; Amberger, 2006). The statistically similar carbon accumulation in the bare plot and the legume amended plots (T_3, T_5, T_6) and their higher levels than in

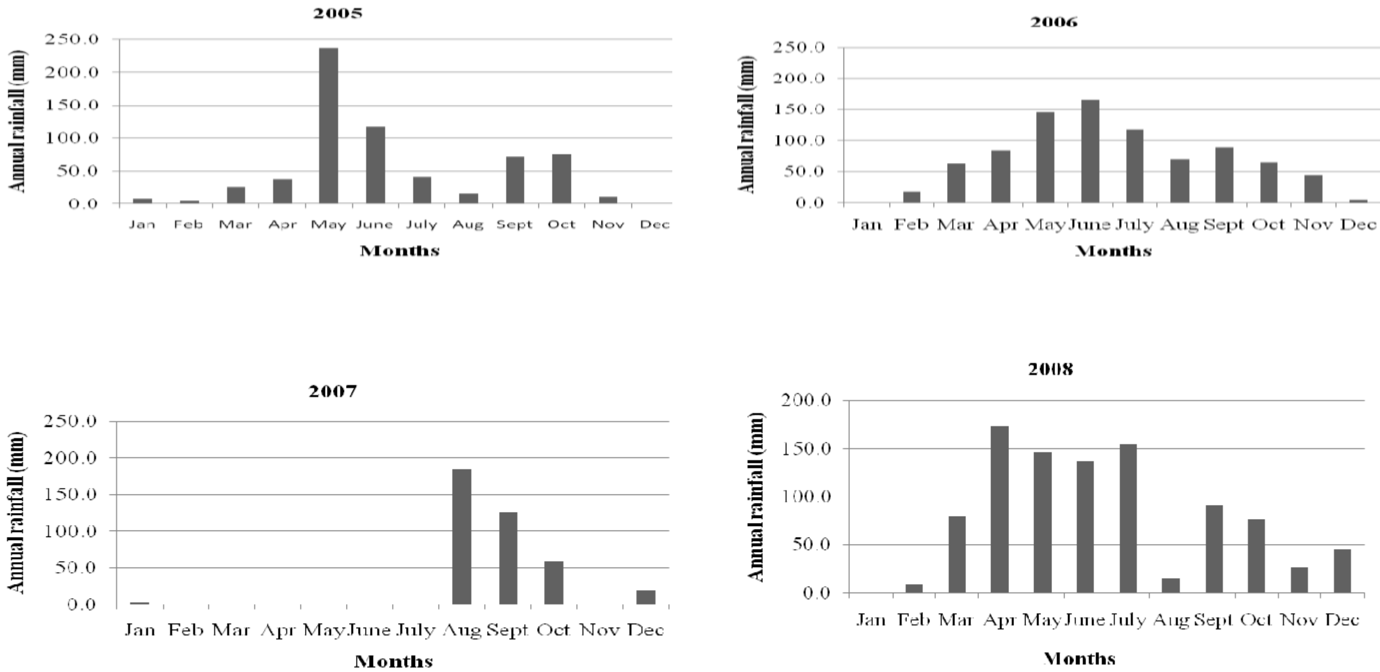

Figure 2. Distribution of annual monthly rainfall at the study sites from 2005 to 2008.

Table 4. Organic carbon accumulation in the soil prior to major season planting.

Treatment	Organic carbon content† ($kg\ ha^{-1}$) LSD (year) = 828.5		
	2006	**2007**	**2008**
T1	15569 ± 215	18928 ± 198	23707 ± 272
T2	17252 ± 266	20188 ± 218	24416 ± 281
T3	20293 ± 326	22442 ± 199	27109 ± 325
T4	19068 ± 264	19688 ± 223	23622 ± 278
T5	18365 ± 216	20579 ± 254	26778 ± 230
T6	18938 ± 219	22571 ± 236	27371 ± 262
T7	17655 ± 248	19864 ± 220	24508 ± 298

LSD (treatment) = 1265.6 (Mean organic carbon accumulation in 2005 = 21750 ± 398 kg/ha).

the natural fallow plots (T_2 and T_7) in 2006 could attest to the fact that it takes time for carbon levels to build up in soils. All the plots had fallowed naturally for about ten years with just a six month break in the fallow for cultivation of maize. The underground biomass which may have accumulated over the ten year fallow period could be masking the result. With continuous application, the plant amended plots may show higher levels of carbon than the bare plot. It must be noted that the effect of the ten-year fallow during the first year of the experiment in 2006 could not be eliminated without disturbing the uniformity of soil, which is an essential factor in assessing the impact of fallow in carbon build up.

At the onset of the major season of 2007, the carbon accumulated in the soil was statistically in the order of $T_3 = T_6 > T_5 = T_2 = T_7 = T_4 > T_1$.The T_3 and T_6 legume treatments had received more than a two-fold increase in their biomass addition in the minor season of 2006 compared to the other plots (T_2, T_5 and T_7) and coupled with their fast rate of decomposition (Adiku et al., 2010), it stands to reason that the T_3 and T_6 treatments accumulated significantly higher levels of carbon. The amount of DM added to the T_5 treatment after the minor season of 2006 was the least (1,743 ± 107 $kg\ ha^{-1}$).However, the carbon accumulated in the T_5 soil at the onset of the major season of 2007 was statistically similar to those of T_2 and T_7.The T_5 soil had been amended with cowpea which was found to have a higher decomposition rate than grass in a related study elsewhere (Adiku et al., 2010).It was noted that the decomposition rate constant values (k_d) for cowpea and grass fallow were 0.020 (d^{-1}) and 0.013 (d^{-1}), respectively. The faster decomposition rate of the cowpea may have influenced the similarity in the level of C in the T_5 soil as in the natural fallow soil despite the lower biomass addition to the former.

Unlike in 2006 when the soil in the control T_4 had higher levels of carbon than the natural fallow plots T_2 and T_7 even though the latter two had had biomass additions, in 2007 the carbon accumulations in the three plots were statistically the same. It thus appears that the longer period of biomass addition to the soil was beginning to have an effect on the carbon accumulation. Just as in 2006, T_1 had the lowest level of carbon accumulations in 2007 thus supporting the earlier alluded harmful effect of burning. Nevertheless, carbon accumulation in the legume fallows, especially for pigeon pea (T_3) and mucuna (T_6) in 2007 was greater than the value at the onset of the experiment suggesting a positive effect of the improved fallow management.

Even though, in the preceding minor season, the cowpea plot had received less dry matter addition than the natural fallow plots, the treatment recorded statistically higher levels of carbon contents than the natural fallow treatments (T_2 and T_7) in the major season of 2008.The carbon levels were statistically similar to those of the other two legume amended plots T_3 and T_6.In fact, the three legume-amended plots had accumulated 27,036 kg ha^{-1} of OC, about 11% more than the average (i.e. 24,462 kg ha^{-1}) of the T_2 and T_7 natural fallow plots. The control which was devoid of plant material had statistically the least carbon contents similar to those of the burnt T1 plots. It is noteworthy that throughout the three year study period, the T_5 plot received the least DM addition each year, yet by 2008 its carbon contents were similar to those of T_3 and T_6.

Apart from T_4 (control treatment), the soil in all the other treatments plots increased significantly in organic carbon contents in 2007 compared to the levels in 2006. However, in 2008, the soil all the treatments including the control recorded significant respective increases in carbon storage compared to the levels in 2007.For all the treatments, it is noticeable that carbon accumulation was greater than the initial carbon content (21,750 ± 398 kg ha^{-1}) at the beginning of the study in 2005.The substantial increase in the carbon contents of the legume and natural fallow plots in 2008, notwithstanding the decrease in DM additions, is ascribed to the relatively longer period (3 years) of organic matter addition to the soil. Notwith-standing the zero addition of plant material, increases in C contents in the control site (T_4) soil were noted. This observation could have been due to decomposition of root biomass. Although, we did not evaluate this process in our study, the observation that roots contribute between 47 to 53 % of above-ground residues (Paul et al., 1999) and also contribute more to soil organic matter turnover than crop residues in land use systems elsewhere (Kätterer, 1999; Barré, 2010; Kätterer et al., 2011) could be a plausible explanation.

Particle size distribution and bulk density

Data on particle size distribution and bulk density of the soil at the various treatment sites at the onset of the major seasons of 2006, 2007 and 2008 are presented in Table 5. In general, particle size distribution of the soils in calgon (the conventional method) under the various treatments for the three-year study period did not change and is similar to the texture of the plough layer of the modal profile (Table 1).The particle size distribution of the soils using water, however, changed over the period. The water dispersible sand fraction increased marginally in most of the treatments in 2007 relative to 2006 with a cor-responding marginal decrease in the silt-sized fraction. In 2008, there was on the average, a 12% increase in the water dispersible sand content in all the treatments with a corresponding 12% decrease in the silt-sized fraction from that of 2007.

The amount of clay-sized fraction generally remained the same throughout the three-year period indicating that the silt-sized fractions were being aggregated to bigger sand-sized fraction by the organic matter addition to the soil. These bigger aggregated fractions which could easily be dispersed by the sodium hexametaphosphate (calgon) to give the true particle sized distribution of the soil were somewhat resistant to water dispersion; hence the observed higher water dispersible sand-sized and lower-silt sized fractions. The higher water dispersible sand fraction coupled with continuous application of DM and build up of organic carbon is an indication that the soil was becoming less erodible and hence more stable. This is corroborated by the high significant negative correlation ($r = -0.89^{**}$; $p < 0.01$) between water dispersible silt and carbon accumulation in the soil. The negative correlation implied that as organic carbon increased the water dispersible silt fraction of the soil decreased resulting in increasing water dispersible sand content with continuous application of organic matter. It thus appears that for this soil, stability was influenced mainly by the amount of silt fraction.

The 0 to 20 cm of the modal profile (in 2005) had a bulk density (BD) of 1.28 Mg m^{-3} which was similar to that of all the soils under the various treatments in 2006. In 2007, the BD values of the plots under fallow ranged from 1.25 to 1.39 Mg m^{-3} whereas the bare plot (T_4) showed a relatively higher value of 1.49 Mg m^{-3}.It is apparent that the lower BD values in the fallow treated plots could be attributed to the effect of root growth and development which increased pore spaces in the soil (White, 2006; Brady and Weil, 2008; NRCS, 2008).The higher BD in the bare plot, in part, could be the result of compaction from rain drops and reduced root activity. In 2008, the bulk density ranged from 1.40 to 1.50 Mg m^{-3} and the same

Table 5. Some physical properties of the soils prior to maize cultivation and after fallow management treatments.

Treatment	Particle size distribution† (%)						BD‡ (Mg m^{-3})
	$Sand_c$	$Silt_c$	$Clay_c$	$Sand_w$	$Silt_w$	$Clay_w$	
2006							
T1	61.9	8.9	29.2	64.3	28.9	6.8	1.28
T2	67.3	6.0	26.7	69.2	26.1	4.7	1.29
T3	66.8	9.0	24.2	74.3	19.9	5.8	1.28
T4	64.8	11.0	24.2	72.1	22.2	5.7	1.32
T5	61.5	9.3	29.2	65.3	30.0	4.7	1.31
T6	64.2	9.9	25.9	67.8	26.4	5.8	1.28
T7	66.7	9.1	24.2	70.0	24.7	5.3	1.29
2007							
T1	65.5	12.3	22.2	68.6	24.2	7.2	1.25
T2	63.5	13.0	23.5	71.0	23.0	6.0	1.27
T3	68.1	12.1	19.8	76.1	19.8	4.1	1.27
T4	64.6	11.9	23.5	71.7	23.6	4.7	1.49
T5	63.3	11.3	25.4	68.4	24.4	7.2	1.34
T6	65.2	10.7	24.1	69.0	24.4	6.6	1.39
T7	66.6	10.7	22.7	71.3	23.4	5.3	1.33
2008							
T1	61.3	6.3	32.5	81.9	12.5	5.6	1.40
T2	66.9	2.5	30.6	83.1	10.0	6.9	1.50
T3	68.9	4.4	28.8	84.4	10.6	5.0	1.40
T4	68.1	3.1	28.8	85.6	9.4	5.0	1.50
T5	63.1	5.0	31.9	80.6	12.5	6.9	1.50
T6	67.3	5.0	27.5	83.8	10.6	5.6	1.40
T7	65.0	4.4	30.6	83.8	11.3	5.0	1.40

+C= Calgon dispersion; w = water dispersion; ‡ BD = bulk density.

observation occurred with T_4 having the highest BD level. The increasing BD with time and continuous OM application were attributed to the increasing content of water dispersible sand fraction. Considering the conversion of silt fraction to sand-size fraction as a result of aggregation, it stands to reason that with time BD was increasing. This is further supported by the significant negative (r = -0.69*) between BD and silt content (water dispersible).

Dispersion ratio

Data on dispersion ratio (DR), an index used to determine the stability of soil aggregates, are presented in Table 6. Dispersion ratio indicates the ease with which the silt and clay particles go into suspension. This depends on the stability of aggregates, which is a function of organic matter content of soils (Tisdall and Oades, 1982; Chaney and Swift, 1986; Haynes et al., 1990; Six et al., 2002, 2004; Bronick and Lal, 2005). A lower DR value means a greater stability of soil and hence less erodibility (Gupta et al., 2006).Tropical soils with DR > 0.15 have been found to be erodible (Onweremadu, 2007).Thus, from our results, soils. (T_1) with DR values of the between 0.47 ± 0.07 and 0.94 ± 0.09 throughout the study period should be susceptible to erosion. With continuous application of DM, however, the DR values progressively decreased from an average of about 0.88 in 2006 to about 0.50 in 2008 for the soils, which was indicative of greater stability and hence decreasing erodibility.

There were no significant differences among the treatments with respect to DR within each year that the treatments were imposed despite the differences in C accumulation in 2006 and 2007.This implies that within a short span of time, the quantity and quality of plant material added to the soil *per se* did not reflect in the stability of the soil. The effect of treatments on stability could, however, be realized with continuous and longer application period.

The T_4 treatment (control) was devoid of plant material

Table 6. The Dispersion ratios (DR) of the soils after fallow management treatments.

Treatment	Dispersion ratios		
	2006	2007	2008
T1	0.94 ± 0.09	0.87 ± 0.07	0.47 ± 0.07
T2	0.94 ± 0.08	0.78 ± 0.08	0.50 ± 0.06
T3	0.76 ± 0.11	0.76 ± 0.10	0.45 ± 0.08
T4	0.80 ± 0.06	0.59 ± 0.07	0.56 ± 0.09
T5	0.90 ± 0.10	0.58 ± 0.08	0.53 ± 0.10
T6	0.90 ± 0.09	0.76 ± 0.10	0.51 ± 0.11
T7	0.91 ± 0.08	0.76 ± 0.09	0.49 ± 0.10

LSD for DR = 0.1318 for treatment and 0.086 for year.

during the minor seasons and was, therefore, not expected to have any significant decrease in DR. On the contrary, its DR decreased significantly from 0.84 ± 0.06 in 2006 to 0.56 ± 0.09 in 2008 (Table 6).This decrease in DR could be caused by compaction of soil from rain drops as reflected in its higher bulk densities in 2006 and 2007 (Table 3).Although the T_1 treatment was similar to T_2 and T_7 due to the fact that it was allowed to fallow naturally during the minor season, this plot had its plant material burnt prior to the maize cultivation as is the common practice in West Africa. Yet, like T_2 and T_7, the DR values in T_1 did not decrease significantly in 2007 from those in 2006 implying that burning (in T_1) did not influence stability of soil aggregates.

In general, the legume amended soils (T_3, T_5 and T_6) showed approximately 42% decrease in the DR values in 2008 compared to values in 2006 while plots with natural fallow (T_1, T_2 and T_7) showed between 46% and 50% decrease in DR within the same period. The decrease in DR in T_4 over the same period of time was only 30%. Strikingly, T_1, the natural fallow with the plant material burnt prior to the cultivation of the crop, had the highest decrease of 50% DR during the study period. Burning likely liberated calcium from the fallow materials and helped to bind the soil particles. This process decreased significantly the DR and hence improved aggregate stability. This calcium liberated into the soil might have acted as a flocculants in the T_1 soil. With continuous rain, however, T_1 may not have DR values similar to those of T_2 and T_7 as calcium which is mobile may either be washed off or leached out. This seemed to agree with the findings of Graham (2010).In a recent study of land quality of acrisols under different management systems in the sub-humid tropics this author noted that calcium exerted great influence on soil aggregate stability after burning of plant material.

There was a significantly high negative correlation (r = -0.87**) between DR and carbon accumulated in the soils similar to what was reported (r = -0.88**) in Nigeria by Onweremadu (2007).The high correlation (that is, -0.87) between organic carbon accumulated and DR implies that for this Acrisol, 76.5% of the DR and hence erodibility is accounted for by organic carbon accumulation and as organic carbon increases erodibility decreases. Studies by several authors in other parts of the tropics (Onweremadu et al., 2007; Barreto et al., 2009; Lawal et al., 2009; Samahadthai et al., 2010) have shown that structural stability of soils was enhanced by organic carbon accumulation.

To be able to determine the contribution of either the legumes planted during fallow or the natural fallow on erodibility, the carbon accumulated in the legume treatments and natural fallow treatments were correlated separately with their respective DR. The coefficient of determination (R^2) values was -0.76 and -0.95 for the legume and the natural fallow treatments, respectively. Thus, 95% of the decrease in DR in the natural fallow plots was accounted for by their organic carbon accumulation compared to 76% in the legume plots. The higher (R^2) values in the natural fallow may explain why the decrease in DR was between 46 and 50% in the natural fallow plots compared to the 42% in the legume plots.

Conclusions

Fallow treatments in the minor season were found to be most appropriate since the land was most often left uncultivated. Different plants have different rates of biomass production and hence varying amounts of organic carbon accumulation in the soil. There is the need to select from among the treatments the best plant species to be used during fallows. The study on the fallow periods in 2005, 2006 and 2007 provided data on relative contributions by each treatment to the improvement in some soil properties. Cowpea is recommended as the most suitable fallow crop in the minor season. In spite of its low biomass additions, its organic carbon accumulations were similar to those of the pigeon pea and mucuna treatments. Additionally, cowpea provides the farmer with an economic yield, the beans, which is a major source of protein in the sub region.

It was obvious from the study that the continuous application of organic matter to soils through minor season fallow cropping increased water dispersible sand fraction as a result of decreasing silt-sized fraction. Decreasing water dispersible silt fraction which was associated with increasing organic carbon accumulation also contributed to increase in bulk density and also dispersion ratio. The highest percentage decrease of 50% dispersion ratio and hence improvement in aggregate stability by the end of the study was recorded in the slash and burn land preparation treatment. It must however be emphasized that this advantage of burning is likely to be short lived. The practice must not be encouraged taking into account the fact that there will be gaseous losses of nutrients and destruction of soil fauna and flora. Though, biomass additions and hence organic carbon accumulations were generally higher in the legume fallow plots ((T_3, T_5 and T_6) than in the natural fallow ones (T_1, T_2 and T_7), these carbon additions did not markedly reflect in the level of decline in dispersion ratio and hence low erodibility of the soils. Organic matter accounted for a relatively greater stability in soils under the natural fallow treatments than in soils under the legume treatment.

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