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Seasonal Variability and Land Use Effects on Aggregate Stability, Shear Strength and Organic Matter Content of an Ultisol

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ABSTRACT

Ultisols of the tropics are characterised bylow crop productivity, severe degradation and variability in their properties due to inappropriate land use practices and seasonal changes. Knowledge of variability in soil properties is important for precision farming, adequate food production and environmental modeling. The major objective of this study was to evaluate the effect of season and land use on the studied properties. The experiment was factorially arranged in randomised complete block design (RCBD), with season, month of sampling and land use, serving as factors. Data were analysed using analysis of variance (ANOVA) and significant means were separated using least significant difference at 5% probability level. Bare fallow had the lowest shear strength (119.62 kN m^{-2}), water stable aggregates (WSA) (33.34 %), soil organic matter (13.95 g kg^{-1}), and bulk density (1.40 g cm^{-3}). Soil under bush fallow had the highest shear strength (136.95 kN m^{-2}) andWSA (38.00 %), and the least silt content (89.35 g kg^{-1}).The shear strength,organic matter and aggregate stability varied moderately (C.V=16.89, 20.26 and 38.43%, respectively). Significant interactions between the season and land use were noted in organic matter content only. Seasonal variations affected shear strength, organic matter, and bulk density significantly (P=0.05).

Keywords: Bare fallow, bush fallow, continuos cassava cultivation, dry and rainy seasons, Ultisols

INTRODUCTION

Ultisols, characterised by high leaching of base–forming cations, very acidic B-horizon, and low fertility (Brady and Weil,1999), are highly weathered but prone to degradation due to excessive rains (Lal, 1987). However, Ultisols do respond to good management (Landon, 1991). Soils are a natural resource of great importance in agriculture, especially for providing crops with nutrients, rooting space and anchorage. Soil, as a scarce commodity, has competition in terms of

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*Corresponding author : E-mail: agimchimaobi@yahoo.com usage other than agriculture (Oluwole, 2011) as a result of population pressure, government policies, market demand, climate change and urbanisation (Valentin *et al.*, 2008). Soil properties are highly variable, show complex interaction, and are sensitive to human activities and agricultural intervention. Variability in soil resources affects patterns of soil process rates (Ettema *et al.*, 1998; Corstanje *et al.*, 2006), resulting in low crop yield, increased cost, land devaluation and degradation (Lal, 1987) .

In Sub-Saharan Africa, soils are characterised by low crop productivity (Eswaran, 1997), and are subject to severe degradation due to inappropriate land use practices (Igwe, 2003; Lal, 2009) and seasonal changes (Singer and Munns, 1999). Several researchers (Geeves *et al.*, 1995; Abbasi *et al.*, 1988; Jirku *et al.*, 2010; Mosayeb *et al.*, 2011) have documented that land use practices have led to changes in the soil physico-chemical properties, especially aggregate stability, soil organic carbon, cation exchange capacity (CEC), and shear strength. The effects of land use on soil properties have also been documented by other researchers. Whilst studying the effects of land use on soil, Aluko and Fagbenro (2000), observed increased pH and organic matter for soils under Gmelina aborea compared to soils under Pinus canaborea, Treculia Africana, agroforestry and fallow. They also observed increased phosphorous (P) in fallow compared to other land use types. Akamigbo and Asadu (2001) reported marked changes in morphological, physical and chemical properties, which accelerates pedogenic processes, and decline in fertility of soil under traditional use when contrasted with forest land. Agim (2010), Uzoho (2011), Ahukaemere *et al*., (2012) and Agim *et al*., (2012) also found significant differences is soil properties.

Aggregate stability, soil organic matter and shear strength are important soil properties that can be used in the study of soil erosion (Brady and Weil, 1999). Soil aggregate stability is an important indicator of the soil's physical quality (Castro Filho *et al*., 2002) and can be affected by land use (Bergkamp and Jongejans, 1988; Cerda 2000). A loss of aggregate stability leads to disintegration, slaking and ultimately soil erosion (Oti, 2002). Shear strength, as an important measure of soil strength, is the ultimate state of stress that a soil or material can sustain before it fails (Singer and Munns, 1999). It is used to describe the maximum strength of soil at which point significant plastic deformation or yielding occurs due to applied shear stress (Atkinson, 1993). It is also a quantitative measure of a soil's internal resistance to externally applied forces before the soil fails. Igwe (2003) noted that in low strength soils, soil erosion, soil loss, surface sealing, crusting, nutrient depletion are prevalent. Chukwuezi (1986) reported that soil detachability directly relates to low shear strength. Soil organic matter is comprised of the product of plant and animal materials that have undergone decomposition processes (Bot and Benites, 2005). Soil organic matter improves the ability of the soil to resist erosion and enables the soil to hold more water.

The driving factor for this study was the lack of knowledge in the critical importance of variability in soil properties, especially in precision farming, and environmental modeling in the area studied. The objectives of this study were to determine the effects of seasons and land use on aggregate stability, shear strength, and organic matter on the studied soil.

MATERIALS AND METHODS

Study Area

This study was carried out at the Federal University of Technology Teaching and Research Farm Owerri, Imo State in South-eastern Nigeria. The farm is located on latitude 05^{o}22’55.5” N and longitude 06^{o}59’ 39.3’’ E, and is 61 m above sea level. The soils were derived from coastal plain sands (Benin formation) (Orajaka, 1975). The topography is almost flat having a slope gradient of between 0 and 2% (Onweremadu and Anikwe, 2007). The existing vegetation is secondary forest (Igbozuruike, 1975). The area lies in the humid tropics with two seasons (dry and rainy/wet), minimum and maximum ambient temperatures of 20^{o}C and 32^{o}C, respectively, and is characterised by an annual rainfall of about 2500 mm bimodially distributed with peaks in the months of July through September and a short dry season in August known as August break (Department of Land Survey and Imo State of Nigeria,1984)

Experimental Design

The experiment was a three-factor factorial experiment arranged in a randomised complete block design (RCBD); the four land usetypes constituted factor A, the season of sampling factor B, whilst the six sampling periods (months) constituted factor C.

Soil Sampling

Random sampling technique was used in collecting soil samples. Soil augers were used to collect soil samples at depths of 0-20 cm. Collected soil samples were air dried, passed through a 2 mm sieve for routine laboratory analysis. Sample collections were carried out at two-monthly intervals from October 2008 to December 2009 (viz. October/November, December/ January, February/March, April/ May, June/July, August/September). There were 6 sampling periods to collect the 72 soil samples used for this study. Core rings were used to collect undisturbed soils for the determination of bulk density.

Land Use Types Studied

There were four land use types included in this study. The first was (i) soil under continuous cultivation (SCC) with cassava (*Manihot* spp.) This soil has been under cultivation for more than 10 years, (ii) Soil under bush fallow (SBF) for more than ten (10) years, (iii) Soil under a pineapple (*Ananas comosus*) orchard (SPO). The orchard was about 10-years old, and (iv) Bare fallow soil (BF) without vegetation. The BF soil wasthe control for this study and was maintained by the constant hand picking of weeds throughout the sampling period. The selection of the different land use types from the same area was to avoid variations introduced by different parent materials in the soils.

Laboratory Analysis

Particle size distribution was determined by the hydrometer method according to the procedure of Gee and Or (2002). Bulk density was measured by the core method (Grossman and Reinsch, 2002). Aggregate stability of water stable aggregates (WSA) larger than 0.5 mm was measured by the wet sieving method of Kemper and Rosenau (1986). Shear strength of the soil was determined by direct shear tests as described by Head (1982). Soil pH was measured potentiometrically in a suspension with a soil to water ratio of 1:2.5 (Hendershot *et al.*, 1993). Organic carbon was determined by the procedure of Nelson and Sommers (1982). Soil organic matter was calculated by multiplying organic carbon with a factor of 1.724.

Data Analyses

Data were analysed using analyses of variance (ANOVA). Least significant difference (LSD) was used to separate significant means at 5% probability. Correlation and regression were carried out using Microsoft Excel 2007. Ranking of the coefficients of variation was done according to the method of Aweto (1982).

RESULTS AND DISCUSSION

Results showed that all the studied soils had sandy loam texture irrespective of land use and season (Table 1), typical of soils in the study area (Enwezor *et al.*, 1990). The sandiness of the studied soils reflected the parent materialfrom which they were formed, namely coastal plain sand (Enwezor *et al.*, 1990). Generally the studied soils had low silt to clay ratio (SCR) ranging from 0.55 to 0.65 (Table 1). SCRs as low as those found in this study indicate soils that are highly weathered (Wambeke, 1962).

Shear Strength

SBF had the highest shear strength (136.95 kN m^{-2}), whilst BF had the lowest strength of 119.62 kN m^{-2} (Table 1). The high value of shear strength found for SBF could be attributed to its increased bulk density, and moisture content. Additionally, Poulos (1989) reported that shear strength of a soil is a result of the basic soil composition (*i.e.*, shape of particles, soil water content, and particle size distribution), state of the soil (*i.e.*, effective normal and shear stresses, void ratio, loose, dense or over consolidated, etc.), soil structure, and loading conditions. The varying climatic factors (Table 6), land use management and parent material of the studied area could have also contributed to the change. The result for BFwas in line with those obtained by Osuji (1985) and Chukwuezi (1986). Shear strength showed moderate variation (CV = 33.80%) (Table 1) in all the studied landuse types and related positively ($r^2 = 0.11$) with organic matter and aggregate stability (Table 5).

TABLE 1
Effect of land use on physico-chemical properties of studied soil

Land use	Sand g kg^{-1}	Silt g kg^{-1}	Clay g kg^{-1}	T.C	SCR	ℓb g cm^{-1}	VMV g kg^{-1}	τ kN m^{-2}	WSA>0.5mm %	pH(H_2O)	SOM
SCC	687.14	112.63	198.02	SL	0.62	1.30	128.86	130.15	37.02	5.12	16.95
SPO	735.47	110.55	195.45	SL	0.61	1.31	116.22	125.17	34.56	5.19	16.15
SBF	724.17	89.35	182.84	SL	0.55	.35	119.36	136.95	38.30	5.06	14.89
BF	697.77	120.17	192.56	SL	0.65	1.40	131.34	119.62	33.40	5.07	13.95
LSD (P=0.05)	NS	15.23*	20.57**		NS	0.05*	NS	NS	NS	0.13*	0.16*
C.V (%)	11.01	51.68	27.85		44.23	8.76	41.60	16.89	16.89	11.15	38.43

SCC=Soil under continuous cultivation, SOP= Soil under pineapple orchard, SBF=Soil under bush fallow, BF= Bare fallow, LSD=Least significant difference, TC=Textural class, SL=Sandy loam, SCR=Silt clay ratio, V.M.C= Volumetric moisture content, SOM=Soil organic matter, ℓb=bulk density, τ=Shear strength, WSA=Water stable aggregates,**=Highly significant, NS=Not significant,*=significant
CV= coefficient of variation; (C.V results were ranked as follows: 50-100% = High variation , 20-49 % = Moderate variation, 1-19% = Little variation, respectively).

Seasonally, shear strength did not differ significantly at the 5% probability level; however higher values occurred in dry rather than in rainy seasons in all the studied landuse types, except for BF (Table 2). Vidrih and Hopkins (1996) state that dryness increases soil strength by reducing the water film between soil particles, which increases inter-particle attraction. Zimbone *et al.* (1996) and Singer and Munns (1991) noted that shear strength decreases with increasing moisture content. The increase in soil shear strength during the dry season has also been attributed to past landuse history, and compaction of near surface of the soils as a result of wetting and drying during the late dry season (Achmad *et al.*, 2003). The percentage reduction of shear strength between the dry and wet seasons were 14.05%, 5.99%, and 5.25% and 10.26% for SCC, SPO, SBF, and BF landuse types, respectively. Additionally, the shear strength reduction in the rainy season is also attributed to the direct impact of rain drops splashing on already saturated soils, affecting its cohesion (Chukwuezi, 1986) and changes in other climatic variables (Table 6). There were no patterns in the monthly variations in shear strength for the various landuse types (Table 3). However, the months

TABLE 2
Effect of season on selected physico-chemical properties of studied soil

Land use	Sand g kg^{-1}	Silt g kg^{-1}	Clay g kg^{-1}	T.C	SCR	ℓb g cm^{-1}	VMV g kg^{-1}	τ kN m^{-2}	WSA>0.5mm %	pH(H_2O)	SOM
Dry Season											
SCC	710.17	113.77	203.93	SL	0.49	1.23	87.48	149.77	34.39	5.51	20.56
SPO	749.84	77.56	72.60	SL	0.58	1.29	55.14	129.04	38.82	5.47	21.42
SBF	753.30	82.64	164.02	SL	0.51	1.33	78.52	140.64	37.07	5.60	20.06
BF	741.63	86.17	193.32	SL	0.48	1.41	69.12	113.44	32.27	5.49	16.63
Rainy Season											
SCC	664.11	139.35	192.10	SL	0.75	1.37	124.86	110.33	39.54	4.73	16.24
SPO	632.99	143.53	218.36	SL	1.06	1.33	116.22	121.30	30.29	4.91	10.87
SBF	695.03	96.06	201.66	SL	0.58	1.37	119.36	133.26	39.54	4.51	9.73
BF	697.77	120.17	192.56	SL	0.74	1.39	131.34	125.80	34.40	4.64	11.26
LSD (P=0.05)	21.62*	23.56*	NS			0.11*	0.04*	NS	NS	NS	0.09*

SCC=Soil under continuous cultivation, SOP= Soil under pineapple orchard, SBF=Soil under bush fallow, BF= Bare fallow, LSD=Least significant difference, TC=Textural class, SL=Sandy loam, SCR=Silt clay ratio, V.M.C= Volumetric moisture content, SOM=Soil organic matter, ℓb=bulk density, τ=Shear strength, WSA=Water stable aggregates,**=Highly significant, NS=Not significant,*=significant

TABLE 3

Distribution of bulk density, shear strength, water stable aggregates and soil organic matter with respect to months of sampling

Nov/Dec	Jan/Feb	March/April	May/June	July/Aug	Sep/Oct	LSD (P=0.05)
Bulk density g cm^{-3}						
SCC	1.24	1.29	1.15	1.43	1.37	
SPO	1.13	1.47	1.26	1.39	1.36	
SBF	1.42	1.30	1.27	1.39	1.43	
BF	1.43	1.47	1.32	1.40	1.43	0.05*
Shear strength (kN m^{-2})						
SCC	189.69	127.50	135.12	94.91	105.15	
SPO	92.90	152.85	141.36	124.16	99.22	
SBF	155.57	155.16	151.20	140.84	101.32	
BF	65.04	148.06	127.22	134.84	95.97	15.40*
Water Stable Aggregates >0.5 mm (%)						
SCC	21.92	53.19	28.80	42.34	43.44	
SPO	31.00	39.74	45.72	35.35	21.73	
SBF	39.47	33.63	38.08	32.29	4.16	
BF	27.48	36.35	32.98	27.99	8.05	NS
Soil organic matter (g kg^{-1})						
SCC	20.29	23.73	17.65	9.75	19.60	
SPO	19.78	27.10	20.94	6.30	11.01	
SBF	12.04	16.40	19.72	6.37	8.48	
BF	5.56	20.23	16.63	9.70	8.50	0.64*

LSD=Least significant difference, MOS=month of sampling, SCC= Soil under continuous cultivation, SPO= Soil under pineapple orchard, SBF=Soil under bush fallow, BF= bare fallow,
* Significant at 5% probability level.

of November to April witnessed increased strength in all the soils studied. The lowest and highest shear strength values for SCC (94.91 and 186.69 kN m^{-2}), SPO (92.90 and 152.85 kN m^{-2}), SBF (101.32 and 155.16 kN m^{-2}) and BF (65.04 and 148.06 kN m^{-2}) occurred in July /August and November/December, November/December and January/February, September/October and January/February, and November/December and January/February, respectively (Table 3). Achmad *et al.*, (2003) also observed a decrease in shear strength from November to January, an increase from January to April and a decrease again from April to July. These results accounted for the significant difference ($P<0.01$) (Table 3) that existed between shear strength and the month of sampling. The results also showed that the interaction between the season and month affected the result of shear strength significantly ($P=0.05$) compared to the interaction effects of other factors (Table 4).

Bulk Density

Results showed that bulk density was highest in BF (1.40 g cm^{-3}). This was followed by SBF (1.35g cm^{-3}), SPO (1.31g cm^{-3}) and, lastly, SCC (1.30 g cm^{-3}) (Table 1). The lower bulk density found in SCC was in line with the findings of Landon (1991).The higher bulk densities found in bare soil was not surprising since bare soil receives the direct impact of rain which leads to surface sealing. deGeus (1973) and Koorevaar *et al.,* (1983), both reported that at high

TABLE 4
Interaction effects on studied soil properties

Soil property	Source of variation	DF	LSD (P=0.05)
Shear strength	Season x month	2	20.12**
	Season x land use	3	1.12^{NS}
	Month x land use	6	0.57^{NS}
	Season x month x land use	6	0.46^{NS}
	Error	48	32319.7
	Total	71	83794.90
WSA >0.5mm	Season x month	2	0.48^{NS}
	Season x land use	3	1.71^{NS}
	Month x land use	6	1.29^{NS}
	Season x month x land use	6	4.49**
	Error	48	79.54
	Total	71	7467.17
Organic matter	Season x month	2	20.43**
	Season x land use	3	6.02*
	Month x land use	6	1.86^{NS}
	Season x month x land use	6	1.93^{NS}
	Error	48	645.48
	Total	71	2769.79

D.F=Degree of freedom, **=Highly significant, *=Significant, NS=Not significant.

bulk densities, pore space, soil compaction and runoff increase whereas water infiltration, root growth and seed emergence are reduced. Bulk densities with respect to months of this study, ranged from 1.15 to 1.43 g cm^{-3}, 1.13 to 1.47 g cm^{-3}, 1.27 to 1.43 g cm^{-3}, and 1.32 to 1.47 g cm^{-3} for SCC, SPO, SBF and BF, respectively (Table 3). These showed that the studied soil groups were not very compact (Landon, 1991).This could be attributed to parent material and climate. Results showed that bulk density increased towards the rainy season in all the studied soils except for BF, where different resultswere found (Table 2). This may account for the lower shear strengths found in this study. Bulk densities varied minimally (CV =8.76%) (Table1) with respect to land use and season of study. Lal (1987) attributes variation in bulk density to variation in particle size and the method adopted in sampling. Organic matter and bulk density have a negative relationship (R= -0.29) (Table 5). Agim *et al*., 2012 found similar results. This implies that an increase in soil organic matter content decreases soil bulk density

TABLE 5
Realationship between soil organic matter, shear strength and aggregate stability

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Soil property	R	r^2
Aggregate stability %	0.17	0.03NS
Shear strength (kN m^{-2})	0.31	0.09*
Aggregate stability and shear strength	0.34	0.11*
Bulk density (g cm^{-3})	0.29	0.08NS

Aggregate stability using water stable aggregates showed significantly (P= 0.05) higher values in SBF (38.30) followed by SCC (37.02%), SPO (34.56%) and BF (33.34%). This trend was also true for the period of sampling except for May/June, where the highest aggregate stability was found in SCC. The highest value of 53.1% occurred in SCC in Jan/Feb whilst the lowest value of 21.73 % for SPO occurred during July/Aug. Mbagwu *et al.*, (1993) pointed out that soils with high WSA percentage values of >0.5 mm are more stable than those with lower WSA >0.5 mm. This therefore meant that SBF soil was more stable than the others soils. Aggregate breakdown of soils is attributed to direct impact of raindrops, clay mineralogy of soils, and vegetation differences (Nwadialo and Mbagwu, 1991). Availability of intact roots without tillage could be another reason for the higher percentage of WSAin SBF. Achmad *et al*., (2003) found similar results. However, the monthly variations in aggregate stability for each landuse type did not follow a particular trend (Table 3). Achmad *et al.,* (2003) found similar results in wheat and corn farms. Past landuse history and changes in climatic elements of the studied area (Table 6) could also be responsible for the variation. Season, month and land use interactions affected aggregate stability significantly (Table 4).

TABLE 6

Mean maximum rainfall and temperature data in Imo State for a 5-year period (2005-2009)

Elements	Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Rainfall (mm)	2009	38.6	71.4	40.1	71.2	273.3	371.2	311.1	423.7	392.4	60.0	293.3	10.0
	2008	0.9	0.0	256.4	238.2	165.4	230.8	328.8	362.8	446.3	183.3	14.8	10.1
	2007	Trace	7.4	57.7	62.1	260.9	397.3	485.4	5090	3030	180.2	42.7	9.6
	2006	89.8	18	167.0	81.9	358.2	454.7	802.5	286.7	479.4	3606	9.2	0.0
	2005	38.3	84.3	103.1	182.2	469.8	500.7	260.0	190.5	490.6	1943	21.5	10.5
Temp.(^{0}C)	2009	33.8	34.3	33.8	34.60	30.50	30.10	30.90	30.50	30.30	30.30	30.20	29.10
	2008	33.5	36.9	35.00	32.20	31.10	30.20	29.10	29.40	29.90	31.30	33.00	33.10
	2007	34.10	35.9	35.10	33.30	33.10	31.60	30.80	30.70	30.80	31.50	32.40	34.00
	2006	34.10	34.8	34.30	35.10	32.20	32.20	29.10	29.50	30.00	31.60	34.06	34.80
	2005	33.90	35.2	34.00	34.30	31.40	31.40	30.80	30.20	31.00	32.10	34.60	34.30

29.70Source: NIMET 2009, Lagos, Nigeria.

Soil Organic Matter

Soil organic matter varied moderately (CV= 38.43%) (Table 1) and was significantly (P=0.05) higher in SCC. The order was CCS (16.95 g kg^{-1}) > SPO (16.15 g kg^{-1}) >SBF (14.89 g kg^{-1}) >BF (13.95 g kg^{-1}) (Table 1). This accounted for the low bulk density exhibited by the SCC. Higher values of organic matter in SCC could be attributed to the addition of organicmanure to the soil whilst cultivation was taking place. It thus implied that the mineralisation of essential minerals will occur to a greater extent in SCC compared to the others. Seasonally, soil organic matter was significantly (P=0.05) higher in the dry season than in rainy season (Table 2) with the percentage decreases being 21%, 49.26%,43.55% and 20.71% in SCC, SPO, SBF and BF, respectively. Increased soil organic matter found during the dry season is attributable to increased temperature, and decreased soil moisture content in the soil during the dry season (Table 5) which invariably affects decomposition, and further mineralisation (Singer and Munns, 1999). Alexandra and Jose (2005) reported high temperature as a key factor that controls the rate of decomposition of plant residues. This result is also corroborated by the positive significant relationship between soil organic matter and temperature distribution of the studied location (*Figures 1-4*). This could also be attributed to environmental conditions and the quality of the residue materials added to the soils

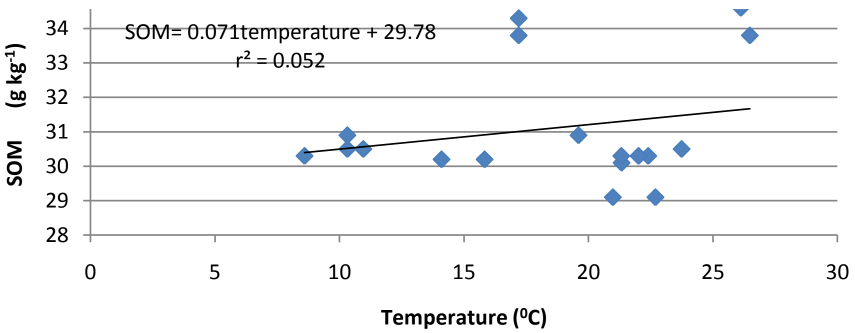

Figure1: Relationship between temperature and soil organic matter in soil under continuous cultivation

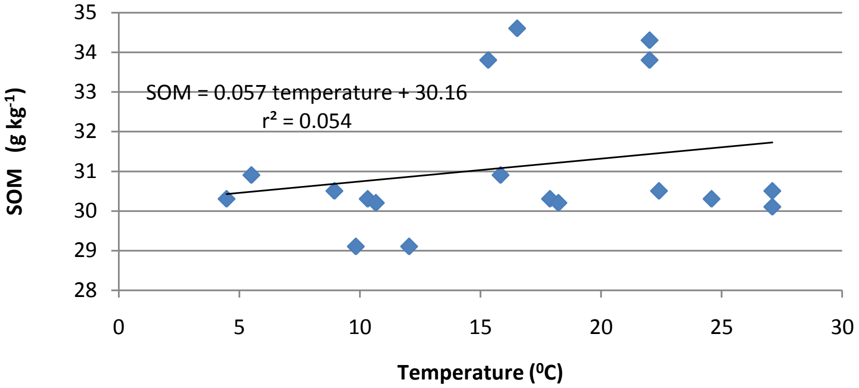

Figure 2: Relationship between temperature and soil organic matter in soil under pineapple cultivation

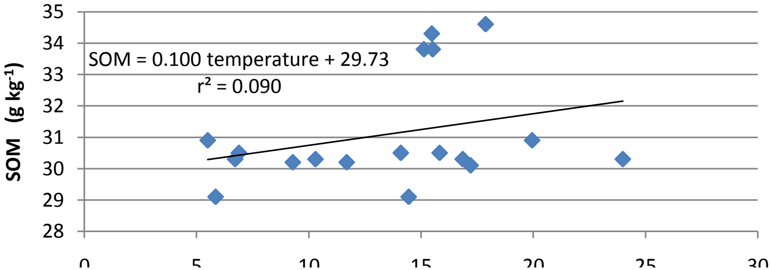

Figure 3: Relationship between temperature and soil organic matter in soil under bush fallow

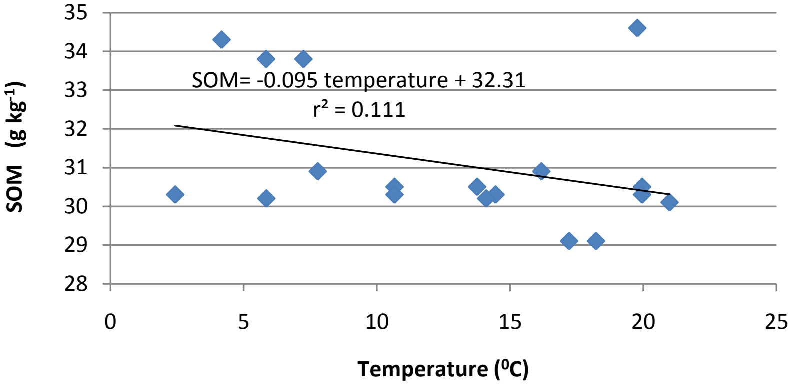

Figure 4: Relationship between temperatureand soil organic matter in bare soil

(Anikwe, 2006; Brady and Weil, 1999). Other contributing factors are cultivation, climate, and land use history. Mbagwu *et al*., (2003) reported that the higher the coarse sand and organic matter, the more stable the soil aggregates. Following this, SCC and SBF should be better aggregated compared to the order two land use types. Results showed significant variations in soil organic matter with the highest value between January/February and July/August in all the studied land use types, except BF where the November/December samples had lower organic matter content (Table 3). Lower values of soil organic matter found during July/August when rainfall was at its peak is attributed to near soil saturation. This condition favours anaerobic conditions (Bot and Benites, 2005). The interaction beween the season and the period of sampling affected soil organic matter significantly (Table 4). Soil organic matter had significant (P=0.05) positive relationship with aggregate stability and shear strength (r^2 = 0.11) (Table 5).

CONCLUSION

This study revealed that season and land use type significantly affected soil organic matter, aggregate stability and shear strength. Among the studied land use types, BF had the lowest value for shear strength (119.62 kN m^{-2}), organic matter (13.95 g kg^{-1}) and percentage WSA >0.5mm (33.34 %), buthad the highest values of silt fraction (120.17 g kg^{-1}) and bulk density (1.40 g cm^{-3}), indicating high erosion potential. SBF had the highest value for shear strength (130.15 kN m^{-2}), WSA(38.30 %) and lowest valuefor silt content indicating low erodibility. SCC contained the highest value of soil organic matter. Soil organic matter had positive relationships with pH (water) (r^2= 0.01), shear strength (r^2=0.09), and the combination of shear strength and WSA (r^2= 0.11). Based on the results where SBF recorded significant improvements in soil properties, this study recommends bush fallowing, but where land scarcity excludes the fallow option, regular application of organic soil amendments will help to improve the physical condition of the soil. Additionally, practices such as agro-forestry and mulching that minimises soil exposure to rainfall are recommended.

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