Tropical and Subtropical Agroecosystems

SOIL PHYSICAL PROPERTIES UNDER DIFFERENT MANAGEMENT SYSTEMS AND ORGANIC MATTER EFFECTS ON SOIL MOISTURE ALONG SOIL CATENA IN SOUTHEASTERN NIGERIA

[PROPIEDADES FISICAS DE SUELOS CON DIFERENTES SISTEMAS DE MANEJO Y EFECTO DE LA MATERIA ORGANICA SOBRE LA HUMEDAD DEL SUELO EN UNA CATENA DE SUELOS DEL SURESTE DE NIGERIA]

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SUMMARY

Some physical properties of the soils under different management systems were determined along a soil catena of three soil series found in Eastern Nigeria. The objective was to determine the effects of management-induced changes on the soil physical properties. Soil samples were taken from three depths (0-20, 20-40 and 40-60 cm) and on three management units made up of cultivated (CC), fallow land (FA) and grazing land (GR). The soils are highly degraded with little silt content and low soil organic matter content. The soil bulk density was highest on 0-20 cm of GR thus affecting the saturated hydraulic conductivity of the soils. Soil moisture content was highest at the soil series on the top of the catena with CC and FA managements retaining more water at the same depth and series. Soil organic carbon (SOC) was correlated with soil moisture at field capacity (FC) (r = 0.53*); also with permanent wilting point (PWP) and available water capacity (AWC) (r = 0.55*; 0.49*). The relationships between the soil moisture contents, SOC and aggregate stability were outlined.

Key words: soil series, management, physical properties, saturated hydraulic conductivity, fallow, grazing, micro aggregate stability.

RESUMEN

Algunas propiedades físicas de suelos con diferentes sistemas de manejo fueron estudiadas en una catena de tres series de suelos del oriente de Nigeria. El objetivo fue determinar el efecto de los cambios inducidos por manejo en las propiedades físicas del suelo. Se tomaron muestras de suelo a tres profundidades (0-20, 20-40 y 40-60 cm) y en tres sistemas de manejo; cultivado (CC), barbecho (FA) y pastoreo (GR). Los suelos están altamente degradados con bajo contenido de limo y materia orgánica. La densidad fue más alta en la región de 0-20 cm en GR, lo que influyó sobre la conductividad hidráulica de los suelos. El contenido de humedad de los suelos fue mayor en la región superior de la catena con CC y FA reteniendo más agua a la misma profundidad y series. El carbono orgánico del suelo (SOC) se correlaciono con la humedad a capacidad de campo (FC) (r = 0.53*); y de manera similar con el punto de marchites permanente (PWP) y la disponibilidad de agua (AWC) (r = 0.55*; 0.49*). Se describen las relaciones entre el contenido de humedad del suelo, SOC y estabilidad del agregado.

Palabras clave: suelo, manejo, propiedades físicas, conductividad hidráulica, pastoreo, micro agregados.

INTRODUCTION

The land system which reoccurs around the Nsukka area in southeastern Nigeria is peculiar in that three prominent and dominant soil series occur in a catenary association (Obihara *et al.,* 1964; Jungerius 1964). However, these soil series are highly degraded, compacted due to structural degradation and leached as a result of the high intensive rainfall and land misuse for agricultural and non-agricultural purposes (Igwe 2004). It has been shown that good soil management options can help in rehabilitating soils that are badly degraded. Sharma and Aggarwal (1984) indicated that soil structure and some other soil physical properties can change under various land management techniques. Recently Salako and Kirchhof (2003) working on Alfisols of southwestern Nigeria remarked that higher infiltration rates were obtained at the topsoil than in the subsoil. They attributed the result to the presence of fewer larger pores below 30 cm soil depth.

Better soil management options can also be related with carbon sequestration. According to Lal *et al*. (1994) there is evidence that reduction in tillage particularly in non-tillage system can result in sequestration of organic carbon. Angers *et al*. (1997) also confirmed that there are marked differences in soil organic carbon in reduced tillage and conventional tillage in cooled temperate eastern Canada. They claimed that most soils under reduced tillage had more soil organic carbon in the top 10 cm than under conventional tillage which was compensated by less soil organic carbon at the lower depths.

The mechanical impedance of a soil is described in terms of soil bulk density and/ or soil strength (Pabin *et al*., 1998). This soil mechanical impedance can be affected by such soil properties as soil moisture content and aggregate stability at macro- and micro levels. There is a direct relationship between an index of aggregate stability and the erodibility of that soil (Farres 1987; Le Bissonnais 1990; Bajracharya *et al*., 1992; Igwe 2003). Aggregate stability was shown by Imeson (1984) to serve as a sensitive indicator of soil degradation. The microaggregate stability indices and particles according to Levy and Miller (1997) are very important in the processes of infiltration, sealing and crust formation, runoff and soil erosion. This all important index of degradation can be modified by land management. Cerda (2000) indicated that aggregate stability indices can be controlled by land use and climate condition. In turn soil organic matter (SOM) has been identified as a major controlling factor in aggregate stability of soils (Angers *et al*., 1997). SOM act as bridge between clay particles and polyvalent cations.

The three reoccurring soil series at Nsukka are highly degraded, with very high runoff rate due to the slope gradient (Obi 1982) yet no known management techniques have been adopted by the farmers and extension agents for better soil management. The objectives of the study were (1) to determine the effect of management-induced changes on soil physical properties (2) to investigate the effect of soil organic carbon and other soil properties on available soil water and particle size fractions. The aim was to recommend the best management option reduce soil degradation and improve soil for sustainable productivity.

MATERIALS AND METHODS

Field study and the soils

The study location is between latitudes 6^{o} 44′ and 6^{o} 55′ N; longitudes 7^{o} 11′ and 7^{o} 28′ E. The climate is characterized by mean annual rainfall of more than 1600 mm with average temperature of 28 ^{o}C. Three soil series (Uvuru, Nsukka and Nkpologu) are very common within the zone were selected for the study. These soil series have been described earlier (Jungerius 1964; Akamigbo and Igwe 1990; Akamigbo *et al*., 1994). The soils have been classified as Typic Paleustult (Soil Survey Staff, 1999) for Nsukka and Nkpologu series while the Uvuru series was classified as Plinthic Kandiustult. The soils are deep and coarse textured with very low cation exchange capacities. Jungerius and Levelt (1964) observed that kaolinite is the major clay mineral of the soils. The soil organic matter content is low, where as leaching, including soil erosion by water, remained major constraints to agricultural production.

Uvuru series occur on the top of the catena, followed by Nsukka series at the middle and Nkpologu series on the toe slope. These soils exist within the University of Nigeria, Nsukka Teaching and Research Farm. They are conventionally cultivated while some parts have been left for grazing animals for teaching and research purposes. The grazing areas are fenced and have not been under tillage since 1975 while some of the lands have been under bush fallow for more than 5 years. On each soil series located along a catena, 3 land management systems were selected; land under cultivation (CC), fallow land (FA) and grazing land (GR). On each sampling location, samples were taken from three depths as follows; 0-20 cm, 20-40 cm and 40-60 cm. From each sampling zone, soil samples were taken in triplicates, making a total of 81 samples sampled for analysis. Both disturbed samples and core samples were taken from each sampling point. The disturbed samples to be used for some analytical parameters were air dried and sieved through 2 mm mesh while the undisturbed core samples were used for moisture content, bulk density and saturated hydraulic conductivity determinations.

Laboratory methods

Particle size distribution of the less than 2-mm fine earth fractions was measured by the hydrometer method as described by Gee and Bauder (1986). The clay obtained from particle size analysis with chemical dispersant is regarded as total clay (TC) and silt as total silt (TSilt), while clay and silt obtained after particle size analysis using deionised water only were the water-dispersible clay (WDC) and water-dispersible silt (WDSi). The soil organic carbon was determined by the Walkley and Black method described by (Nelson and Sommers, 1982). Dispersion ratio which is an index of soil dispersion was calculated as;

$$\text{Dispersion ratio (DR)} = [(\text{WDSi}+\text{WDC}) / (\text{TSilt}+\text{TC})] \quad (1)$$

Also clay dispersion ratio was derived from the formula,

$$\text{Clay dispersion ratio (CDR)} = \%\text{WDC} / \%\text{TC} \quad (2)$$

The higher the CDR and DR, the more the ability of the soil to disperse. The soil saturated hydraulic conductivity was measured using Klute and Dirksen method (1986). Soil bulk density was measured by the core method (Blake and Hartge, 1986). The soil moisture contents at 0.1 and 1.5 MPa suction were determined by Klute (1986) method while the available water capacity was calculated as the difference between moisture retention at 0.1 and 1.5 MPa [i.e. field capacity (FC) and permanent wilting point (PWP)].

An analysis of variance of each soil properties within each depth was performed on the soil data generated from the laboratory. The differences among the mean values were tested with the LSD. Also a correlation coefficient matrix of some of the soil properties tested were developed using the SPSS.10 computer package. The aim was to assess their relationship.

RESULTS

Particle size distribution

The soil particle size distribution for the soils across the three soil series and the management systems is presented (Table 1). In all the soil series across the catena, the clay contents increased with depth on the average except on the mid slope series where the mean values dropped and increased again. The sand content decreased with depth while the silt content showed no significant change with depth. On the whole there are some significant differences between the clay content in the three soil series and with management systems. The soil series on the mid slope of the catena has more clay while the more clay contents were observed in the grazing field (Table 1). Also significant difference occurred within the soil series and management interactions.

More silt content was observed in the top of the catena on 0-20 cm in the 20-40 cm more silt were obtained on the top and mid slope of the catena. The GR management system also produced more silt across the depth and soil series. Significant differences also occurred within the soil series, management systems and their interactions. The same trend, which was observed in the other particle sizes, was the reverse in the sand content in terms of the quantity and pattern within the depth.

Table 1. Soil particle size distribution at three soil depths under different management systems.

Group	Management	Particle-size distribution								
		0-20 cm			20-40 cm			40-60 cm		
		Clay	Silt	Sand	Clay	Silt	Sand	Clay	Silt	Sand
		%								
Top	CC	18	8	74	18	6	76	24	3	73
	FA	12	6	82	16	10	74	18	8	74
	GR	14	13	73	22	13	65	24	9	67
	Mean	14.67	9.0	76.3	18.7	9.7	71.67	22.0	6.67	71.33
Mid	CC	14	4	82	14	6	80	20	2	78
	FA	14	3	83	16	3	81	18	7	75
	GR	26	1	73	20	17	63	32	3	62
	Mean	18.0	2.67	79.3	16.7	8.7	74.67	23.33	4.0	71.67
Toe	CC	14	3	82	19	3	78	19	3	78
	FA	12	2	86	18	3	79	20	1	79
	GR	12	2	86	16	4	80	16	4	80
	Mean	12.67	2.33	84.67	17.7	3.3	79.0	18.33	2.67	79.0
Avg.	CC	15.3	5.0	79.3	17.0	5.0	77.0	21.0	2.7	76.3
	FA	12.7	3.7	83.7	16.7	5.3	78.0	18.7	5.3	76.0
	GR	17.3	5.3	77.3	19.3	11.3	69.3	24.0	5.3	69.7
LSD (0.05)	Group (S)	3.12	4.3	4.9	1.2	4.0	4.3	3.0	3.6	5.0
	Management (M)	2.7	1.0	3.8	1.6	4.2	5.5	3.1	1.7	4.3
	S x M	1.8	2.0	2.8	0.9	2.5	3.1	1.9	1.3	3.0

CC= cultivated; FA= fallow; GR= grazing

Bulk density and saturated hydraulic conductivity

Higher bulk density was generally obtained on the 0-20 cm soils of mid sloe and toe slope soil series than the top slope of the catena. In the 20-40 cm depth the trend was like the 0-20 cm however, in the 40-60 cm higher bulk density was obtained from the top slope than in the mid and toe slope catena (Table 2). On the top soil (0-20 cm), the grazing land use (GR) had higher bulk density followed by the fallow system, while the cultivated fields have lower bulk density. In the 20-40 cm and the 40-60 cm depth the bulk density was highest in FA followed by GR and the CC being the list (Table 2). There was significant difference at series (group), management and group x management interaction. The lower bulk density obtained for the cultivated soils is a positive attribute in terms of soil structural development.

The hydraulic conductivity (K*sat*) values within the soil series and across depth are presented (Table 2). Within the 0-20 cm highest K*sat* was obtained on the top slope while there was no significant difference between the mid and toe slope soil series. The same trend was also obtained for 20-40 cm depth. In the 40-60 cm depth more K*sat* was recorded for mid slope where as the top and toe slope had no significant difference in their K*sat.* The CC and FA had had higher K*sat* at 0-20 cm than the GR. In the 20-40 cm the highest K*sat* was observed also on CC, followed by FA and GR. The K*sat* in 40-60 cm indicated that CC> FA> GR (Table 2). Generally, the bulk density influenced the K*sat* to the extent that the soils with higher bulk density were having correspondingly lower K*sat*. All these also affect both the micro and macro porosity of the soil including the tensile strength of the soil.

Table 2. Bulk density and saturated hydraulic conductivity at three soil depths under different management systems.

Group	Management	0-20 cm		20-40 cm		40-60 cm	
		BD Mg m^{-3}	K*sat* cm h^{-1}	BD Mg m^{-3}	K*sat* cm h^{-1}	BD Mg m^{-3}	K*sat* cm h^{-1}
Top	CC	1.32	1.78	1.27	2.59	1.40	0.30
	FA	1.40	1.37	1.21	0.79	1.75	0.08
	GR	1.58	0.93	1.35	0.22	1.78	0.12
	Mean	1.43	1.36	1.28	1.20	1.64	0.17
Mid	CC	1.46	0.84	1.64	0.36	1.49	0.16
	FA	1.67	0.12	1.70	0.06	1.49	0.32
	GR	1.51	0.05	1.37	0.07	1.40	0.46
	Mean	1.55	0.34	1.57	0.16	1.46	0.31
Toe	CC	1.55	0.11	1.45	0.30	1.49	0.21
	FA	1.44	0.74	1.65	0.15	1.68	0.01
	GR	1.60	0.41	1.75	0.15	1.56	0.06
	Mean	1.53	0.42	1.62	0.20	1.58	0.09
Avg.	CC	1.44	0.91	1.45	1.08	1.46	0.22
	FA	1.50	0.74	1.52	0.33	1.64	0.14
	GR	1.56	0.46	1.49	0.15	1.58	0.21
LSD (0.05)	Group (S)	0.07	0.66	0.20	0.70	0.11	0.13
	Management (M)	0.07	0.26	0.04	0.60	0.10	0.05
	S x M	0.05	0.32	0.10	0.40	0.07	0.06

BD = bulk density; K*sat*= saturated hydraulic conductivity; CC= cultivated; FA= fallow; GR= grazing

Soil moisture contents

The values of soil moisture content at field capacity (FC), permanent wilting point (PWP) and available water capacity (AWC) are shown (Table 3). At the 0-20 cm soil depth, the soil moisture at FC decreased along the catena while CC and FA were higher than the GR. Highest value was obtained for FC at 20-40 cm depth at the top slope while the mid and toe slope soil series with lower values were not significantly different. In the 40-60 cm depth the soil moisture at FC showed that mid slope > top slope > toe slope, while CC > GR = FA (Table 3). In the PWP of 0-20 cm, top slope> toe slope>mid slope. At the same depth (0-20 cm) CC = FA > GR while CC > GR > FA at 20-40 cm depth. Across the series the top slope > mid slope = toe slope. Within the 40-60 cm depth the moisture content at PWP was highest in mid slope and top slope followed by toe slope. The PWP of CC at this depth (40-60 cm) was greater than GR = FA. The available water capacity showed that at 0-20 cm top slope soil series = mid slope soil series > toe slope series. At the same time CC > FA = GR while, at 20-40 cm depth top slope soil series > mid slope series =

toe slope series. The AWC at that depth was highest in CC followed by GR and FA. AWC was higher at 40-60 cm depth in top and mid slopes than in toe slope. At 40-60 cm depth AWC was higher on the top and mid slopes soil series than the toe slope and also higher across CC management system than the GR and FA (Table 3).

Table 3. Moisture contents and available water capacity at three soil depths under different management systems.

Group	Management	Moisture Contents								
		0-20 cm			20-40 cm			40-60 cm		
		FC	PWP	AWC	FC	PWP	AWC	FC	PWP	AWC
		%								
Top	CC	28.0	13.5	14.5	32.4	16.3	16.1	24.6	13.2	14.4
	FA	24.9	11.4	13.5	30.8	15.2	15.6	16.2	5.8	10.4
	GR	18.7	7.5	11.2	29.1	14.0	15.1	16.0	5.7	10.3
	Mean	23.9	10.8	13.1	30.8	15.2	15.6	18.9	8.2	11.7
Mid	CC	28.0	9.4	18.6	18.3	7.2	11.1	20.6	8.6	12.0
	FA	17.8	6.9	10.9	13.2	3.9	9.3	16.8	6.2	10.6
	GR	19.2	7.7	11.5	22.0	9.6	12.4	23.0	10.2	12.8
	Mean	21.7	8.0	13.7	17.8	6.9	10.9	20.1	8.3	11.8
Toe	CC	18.6	7.4	11.2	21.4	9.1	12.3	20.2	8.4	11.8
	FA	22.6	10.0	12.6	18.3	7.2	11.1	14.2	4.5	9.7
	GR	17.7	6.8	10.9	13.0	3.7	9.3	18.3	7.2	11.1
	Mean	19.6	8.1	11.6	17.6	6.7	10.9	17.6	6.7	10.9
Avg.	CC	24.9	10.1	14.8	20.0	10.9	13.2	21.8	10.1	12.7
	FA	21.8	9.4	12.3	20.8	8.8	12.0	15.7	5.5	10.2
	GR	18.5	7.3	11.2	21.4	9.1	12.3	19.1	7.7	11.4
LSD (0.05)	Group (S)	2.5	1.8	1.2	8.7	5.6	3.1	1.4	1.1	0.56
	Management (M)	3.7	1.7	2.2	0.82	1.3	0.7	3.5	2.7	1.40
	S x M	2.0	1.1	1.1	4.0	2.6	1.4	1.7	1.3	0.69

CC= cultivated; FA= fallow; GR= grazing; FC = moisture content at field capacity; PWP = moisture content at permanent wilting point; AWC = available water content.

Soil organic carbon concentrations and microaggregate stability indices

The soil organic carbon (SOC) concentrations with depth and across management systems are shown (Table 4). The SOC values indicate that significant differences occur with series and across management systems (Table 4). Generally, more SOC were obtained on the soil series on the top slope of the catena than the other two soil series. In all cases, highest SOC concentration occurred on the 0-20 cm soil depth. SOC positively correlated significantly with moisture content at FC, PWP, AWC, DR and silt content (Table 6). The soil bulk density also negatively correlated significantly with FC, PWP and AWC (r= -0.93; -0.95 and -0.92), respectively.

The values of water dispersible clay (WDC) and their levels of significance are shown (Table 5). Significant differences occurred across management systems, but not on the series at 0-20 cm depth. Also the range and values for the clay dispersion ratio (CDR) and the dispersion ratio (DR) for the series depths and the management systems are shown. The levels of significance indicate that FA = GR > CC for CDR at 0-20 cm while toe slope had most DR and CDR at the same depth. This is an important indication of the rate of soil loss at this point and levels of management. The higher the CDR and the DR the greater the ability of the soil to degrade and lost in runoff.

Table 4. Soil organic carbon concentration at three soil depths under different management system.

Group	Management	Soil Organic Carbon concentration		
		0-20 cm	20-40 cm	40-60 cm
			$g\ kg^{-1}$	
Top	CC	19.2	15.6	11.3
	FA	27.3	23.1	17.2
	GR	28.7	19.9	5.9
	Mean	25.1	19.5	11.5
Mid	CC	6.3	5.5	5.1
	FA	6.6	5.5	5.9
	GR	10.2	7.8	6.6
	Mean	7.7	6.3	5.9
Toe	CC	11.3	10.2	5.9
	FA	10.6	5.1	6.3
	GR	7.4	7.0	5.9
	Mean	9.8	7.4	6.0
Avg.	CC	12.3	10.4	7.4
	FA	14.8	11.2	9.8
	GR	15.4	11.6	6.1
LSD (0.05)	Group (S)	10.96	8.46	3.70
	Management (M)	1.90	0.71	2.17
	S x M	5.00	3.80	1.92

CC= cultivated; FA= fallow; GR= grazing;

Table 5. Microaggregate stability at three soil depths under different management system.

Group	Management	Microaggregate Indices								
		0-20 cm			20-40 cm			40-60 cm		
		WDC %	CDR	DR	WDC %	CDR	DR	WDC %	CDR	DR
Top	CC	10	0.56	0.50	2	0.11	0.29	8	0.36	0.48
	FA	8	0.67	0.94	8	0.50	0.50	8	0.44	0.42
	GR	8	0.57	0.56	10	0.45	0.37	8	0.33	0.45
	Mean	8.7	0.60	0.67	6.7	0.35	0.39	8	0.38	0.45
Mid	CC	6	0.43	0.61	6	0.43	0.55	6	0.30	0.41
	FA	8	0.21	0.65	6	0.38	0.47	6	0.33	0.44
	GR	6	0.23	0.41	10	0.50	0.35	10	0.31	0.43
	Mean	6.7	0.29	0.56	7.3	0.44	0.46	7.3	0.31	0.43
Toe	CC	6	0.50	0.53	10	0.31	0.68	10	0.70	0.77
	FA	6	0.80	0.64	12	0.42	0.81	12	0.25	0.71
	GR	10	0.83	0.93	14	0.88	0.85	12	0.75	0.75
	Mean	7.3	0.71	0.70	12.0	0.54	0.78	11.3	0.57	0.74
Avg.	CC	7.3	0.50	0.55	6.0	0.28	0.51	8.0	0.45	0.55
	FA	7.3	0.56	0.74	8.7	0.43	0.59	8.7	0.34	0.52
	GR	8.0	0.54	0.63	11.3	0.61	0.52	9.5	0.46	0.54
LSD (0.05)	Group (S)	2.05	0.44	0.15	5.80	0.19	0.24	2.5	0.16	0.20
	Management (M)	0.50	0.04	0.10	3.06	0.19	0.05	0.9	0.08	0.02
	S x M	0.60	0.11	0.06	2.03	0.10	0.11	1.2	0.08	0.09

WDC= water-dispersible clay; CDR= clay-dispersion index; DR= dispersion ratio; CC= cultivated; FA= fallow; GR= grazing.

Table 6. Correlation coefficient matrix of soil water content and some soil properties

	FC	PWP	AWC	BD	SOC	CLAY	SILT	SAND
FC	-							
PWP	0.99*	-						
AWC	0.99*	0.97*	-					
BD	-0.93*	-0.95*	-0.92*	-				
SOC	0.53*	0.55*	0.49*	-0.50*	-			
CLAY	0.09	0.14	0.08	-0.14	-0.15	-		
SILT	0.24	0.23	0.21	-0.24	0.39*	-0.02	-	
SAND	-0.27	-0.32	-0.024	0.32	-0.24	-0.80*	-0.47*	-
Ksat	0.12	0.06	0.13	0.08	0.19	-0.31	0.25	0.11
DR	-0.29	-0.31	-0.27	0.33*	-0.13	-0.60*	-0.31	0.68*
CDR	-0.01	-0.01	-0.01	-0.02	0.24	-0.54	0.24	0.29

*significant $p<0.05$; FC = moisture content at field capacity; PWP= moisture content at permanent wilting point; AWC= available water capacity; BD= bulk density; SOC= soil organic carbon content; DR = dispersion ratio; CDR = clay dispersion ratio; *Ksat* = saturated hydraulic conductivity.

DISCUSSION

Particle size distribution bulk density and saturated hydraulic conductivity

The overall higher average clay content (18%) was found on the 0-20 cm of the mid slope soil series was as a result of the position on the landscape. Colluviation and even accumulation of fine materials from run off could be trapped at this point thus increasing the clay content of the soil at that point. Also the GR and the CC management systems seem to have trapped finer materials at all the depths. This may not have been due to pedogenesis but as a result of the inversion of soil materials during cultivation and tillage. The GR managed system has remained stable for some time due to compaction and non-tillage of the soil thus creating very stable aggregates that does not disperse easily. Also the constant dung supply from the livestock grazing on the land contributes in no small measure to the SOM economy of the soils. The SOM is known to be a good aggregate stabilizing agent and in this case can contribute significantly to the dispersion or flocculation of the soil aggregates. When soil disperses a lot of finer particles are liberated and lost as sediments in runoff.

The best soil series in terms of the lower bulk density especially on the top soil was the soil series located on top of the catena. The state of the soil bulk density reflects on the porosity, *Ksat*, sealing, crusting and soil strength. Higher bulk density results in lower porosity and lower saturated hydraulic conductivity and soil strength which affect the erodibility. Again this situation may be linked to the cohesiveness of the soil particles. The low bulk density also reflected on the saturated hydraulic conductivity. The soil structure at this soil series was better than the other soil series. The highest bulk density especially 0-20 cm of the grazing field could be attributed to the high animal traffic common on this system. Asadu *et al*. (1999) observed very significant difference in bulk density, hydraulic conductivity and porosity of cattle grazing field and non-cattle grazing field in Eastern Nigeria. In all cases the cattle grazing fields had more bulk density, low hydraulic conductivity and low porosity. In southwestern Nigeria Salako and Kirchhof (2003) attributed the higher infiltration rate obtained on the 0-30 cm of the soil as a result of larger pores on the surface than below the 30 cm soil. High bulk density observed for the FA and GR form major mechanical impedance of the soils. This impedance will constitute a major constraint to root development, aeration, fluid transmission and ideal soil tilth for favourable crop management.

Soil moisture contents and soil organic carbon

The higher moisture contents at FC, PWP and AWC observed at the 0-20 cm of the soils in all the soil series may be attributed to higher organic matter contents observed at that depth for all the series irrespective of management systems. The correlation coefficients indicate that all the different moisture retention levels increased as the amount of SOC was increasing in the soil. Many researchers (Bauer and Black 1992; Zhang *et al*., 2001) have attributed the relative higher contents of water and other soil properties due mainly to soil organic matter content and a little contribution from the clay content. Soil organic carbon in this study correlated significantly with all the fractions of moisture content analyzed. Also the soils with high SOC had highest average soil moisture at 0-20 cm. Bauer and Black (1992) showed that in the soils they studied in the United States of America that a unit increase in SOC concentration caused a relatively larger increase in available water content. The SOC does not determine only the extent of moisture content but what may be described as soil wettability. This is because the SOC imparts to the soil the characteristics of repelling water or hydrophobicity and moisture absorption depending on the properties of the soil. This property therefore reflects on the hydraulic conductivity, runoff and infiltration rate of the soil. Although soils had higher amount of SOC in GR than in other managements yet with the lowest values of FC, PWP and AWC. This may be attributed to the relatively higher bulk density of the soils at the management system and this expectedly will lead to low total porosity due to compaction caused by grazing and trampling of animals. Moreover, the soil moisture content absorbed by the organic materials may have contributed in assuring the cohesiveness of the soil aggregates. Thus the stability of the aggregates influences the potential vulnerability of the soil to erosive forces.

Microaggregate stability indices

Generally, the WDC is low and not significant difference among the series at 0-20 cm depth. However, higher WDC was obtained at GR than the other two management systems, indicating that the GR may slake more than the other management systems. This may be so because of the distortion of the aggregates by animal traffic and the weakness of the aggregates upon submerging with water. The soil series on the top have the tendency to disperse more than the rest. Therefore taking into consideration the landscape and the higher WDC of the soils found at that point, this soil series may erode more than the other two soil series lower on the soil catena.

The other two microaggregate stability indices the CDR and DR all indicated that the toe slope soil series have highest values than the mid-slope and top slope series. They failed to agree in their prediction of erodibility on the management system, having different values. Bajracharya *et al*. (1992) indicated that the CDR and DR predicted erodibility very accurately in some Ohio soils in the United States than the other parameters like the particle size distribution. Also, Igwe (2003) applied these two parameters to predict the erodibility of rainforest soils in Nigeria. If these aggregate stability indices accepted therefore, as estimators of potential soil erosion hazard, it will be taken that for erosion prediction using CDR and DR, these soils will erode in the following order toe slope soil series >top slope soil series > mid slope soil series. When the management systems were considered, they will erode in the following order, FA > GR > CC. It should be noted that this prediction is based on the values of these indices on 0-20 cm layer.

CONCLUSION

The grazing management system (GR) had higher bulk density on the top soil than the other management systems. The pattern of bulk density reflected on the saturated hydraulic conductivity and perhaps the porosity of the soil. The soils with high bulk density had lower *Ksat*. The moisture content at field capacity (FC) was highest at the soil series on top of the catena, with CC and FA retaining more water at FC than GR. The CC had more moisture at FC than FA and GR. Also moisture content at PWP was more at the top slope, followed by toe slope and finally the mid slope. While the PWP was highest at 0-20 cm on CC > FA > GR. This was also the trend in the AWC

The soils were low in their silt contents and were highly degrades leaving behind soils with low nutrient and organic matter contents. Soil moisture at FC, PWP and AWC positively correlated significantly with SOC, but negatively correlated with bulk density.

This relationship to a large extent described the degree of moisture absorption and retention of these soils. The DR and CDR especially on the top soil (0-20 cm) indicate erodibility preference of the soils as follows toe slope soil series > top slope series > mid slope series.

The best management option was CC at mid slope with adequate soil management practices in place followed by a well planned fallow with leguminous cover crops to help in regenerating the soil quality. Grazing should be avoided as it may lead to soil erosion especially at steep gradient and high CDR and DR.

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