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Saturated hydraulic conductivity and water-stable aggregates in some forest reserves of Southwestern Nigeria

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ABSTRACT

A study was carried out along a toposequence in three forest reserves under Teak and Gmelina of Osun Grove, Onigambari, and Omo in south Western Nigeria to evaluate changes in saturated hydraulic conductivity (Ksat) and percent soil water-stable aggregates (WSA%). Three points: upper slope, middle slope, and lower slope were delineated and samples for soil analysis were collected from pedogenetic horizon using core samplers and auger. Samples were analyzed for soil properties like; Ksat and WSA (%) Data from the analysis were subjected to ANOVA using GenStat and means were separated using Duncan's multiple range test at P <0.05. Results indicated that there were significant differences in the saturated hydraulic conductivity both under teak and Gmelina plantation along toposequence at Onigambari and Osun grove. But at area J4, upper slope subsurface soil under Gmelina plantation and lower slope surface soil were superior to other slope segments. Meanwhile, middle slope subsurface soil and upper slope surface soil under teak plantation were significantly different from other slope positions. The structural stability and erosion resistance of the soil in area J4 were higher than those of the soil in the Onigambari and Osun sacred grove.

INTRODUCTION

Soil aggregate stability is defined as the resistance of soil structure against mechanical or physical and chemical destructive forces (Duniway, *et. al.,* 2009). The distribution and stability of soil aggregates are closely related to the erosion resistance of soil and, therefore, are effective indicators of erosion sensitivity (Guo *et al*., 2007; Valmis *et al*., 2005; Rachman *et al*., 2003). According to Le Bissonnais (1996), soil erosion is primarily a result of the destruction of soil aggregates. Young (1980) and Bryan (2000) observed that aggregate stability affects the erodibility and nutrient holding capacity of the soil. Soil structure is one of the most important soil characteristics that control plant growth as it influences the root penetration, soil temperature and gas diffusion, water transport, and seedling emergence. Soil structure defines the combination or arrangement of primary soil particles into compound elements. Thus soil texture, soil structure, the type of clay mineral, organic matter content, and type, cementing agents as well as cropping history of a particular land collectively influence the aggregate stability (Goldberg *et. al*., 1988).

The mean weight diameter (MWD) is commonly used to express aggregate stability. It determines the size distribution of aggregates and is essentially a measure of macroaggregate stability as the aggregates that remained on each sieve must be stable to the wetting and sieving processes (Amezketa 1999). High values of Mean Weight Diameter (MWD) indicate the dominance of less erodible and large aggregates of the soil (Piccolo *et al*., 1997). The excess litter on the topsoil; the high organic matter contents; and the good water, Heat, and air conditions of the soil contributed to the formation of large aggregates (Tisdall and Oades, 1982; Xiao *et al*., 2008).

All high economic trees when effectively managed can

help eradicate or reduce the global economic recess of many nations like Nigeria. Therefore, the objective of this study was to evaluate changes in saturated hydraulic conductivity (Ksat) and percent soil water-stable aggregates (WSA%) and to determine the relationship between aggregate stability, hydraulic conductivity, and mean weight diameter of soils under Teak and Gmelina plantations, to obtain repeatable soil quality information which if applied would enable sustainable productivity of these plantation trees.

2.0. Materials and Methods

2.1. Study Site

Soils from pedogenic horizons and surface soils at 0-15 cm, 15-30 cm depth were collected from three forest reserves. The forest reserves include Omo Forest Reserve (area J4) in Ogun State, Osun sacred grove in Osun State, and Onigambari Forest Reserves in Oyo State, all in South-Western Nigeria. Osun Sacred Grove is located approximately between latitudes 7˚44'50.0" - 7˚46'00.0" N and longitudes 4˚32'40"-4˚33'40" E. The average rainfall is between 1250 mm and 1450 mm per annum. The temperature in this area is almost uniform throughout the year with very little deviations from the mean annual temperature of 27^{0}C. Onigambari Forest Reserve is located between latitude 7°26′ N and longitude 3° 51′E. The mean annual rainfall is about 1300 mm. The mean annual temperature is about 27^{o}C with no marked seasonal or monthly departure from the annual average.

Omo Forest Reserve is situated between latitudes 6^o 35$^{'}$ to 7^o 05$^{'}$ N and 4^o 19$^{'}$ to 4^o 40$^{'}$ E. The reserve has a mean annual rainfall range of 1,200 to 1,600 mm per year. Mean annual temperature ranges between 21 – 28^{o}C within the South-West zone of Nigeria

2.2. Sample collection and Laboratory Analysis

Soil samples were collected from the plantations using a soil auger at two depths (0 -15 cm, 15 – 30 cm). Profile pits were also dug along a toposequence and samples were collected according to the pedogenetic horizon for laboratory analysis. Particle size analysis was determined using the hydrometer method (Bouyoucos, 1962).

Saturated hydraulic conductivity (Ks) in cm hr^{-1}was measured by the constant head soil core method as described by Reynolds (1993), which is the transpose of Darcy's equation for vertical flow liquid. Ks were then calculated from the relationship:

$$Ks = QL/(At)(L + h)$$

Where;

Q = the quantity of water discharge at equilibrium,

L = length of soil core,

A= cross-sectional area of the soil core,

T = time taken to reach equilibrium,

H = the head of water above the soil core.

Aggregate size distribution and stability were determined using the wet-sieving method (Kemper and Rosenau, 1986). Fifty (50) grams of air-dried soil pre- sieved was placed on a set of sieves arranged in the following order; 2.0 mm,1.0 mm, 0.5 mm, 0.25 mm, and < 0.25 mm. The whole set was pre-soaked in water for 10 minutes. This was then oscillated vertically 20 times at an amplitude of 5 cm at 5 strokes per minute.

The quantity of aggregate retained in each sieve was oven-dried and weighed to determine the percent water-stable aggregate (% WSA) using the below relationship.

%WSA = (Ma + s - Ms/Mt - Ms) * 100

Where

(Ma +s) = the mass of the resistant aggregates and stone in gram (g),

Ms = the mass of the stone fraction alone

Mt = the total mass of the sieved soil (g).

Mean weight diameter (MWD) was determined using data obtained from the percent water-stable aggregates (% WSA) above.

MWD = $\sum$XiWi

Where

Xi = the diameter of each fraction (mm)

Wi = the proportion of the total sample weight (WSA) in the corresponding size fractions after removing stone weight.

2.3. Data Analysis

Data collected were subjected to analysis of variance (ANOVA) using GenSat V package and Means were separated using Duncan's multiple range test at 5% probability level.

3.0. Results and Discussions

Soil aggregates measured by percent mean weight diameter, (MWD %) were highly stable in the teak and Gmelina plantation at Omo forest reserve, Area J4 (Table 4).

In terms of water-stable aggregate (WSA) and mean weight diameter, Young (2001) and Bryan (2000) reported that aggregate stability affects the erodibility and nutrient holding capacity of the soil. It was observed that Omo forest reserve, area J4 had a higher quantity of soil aggregates within 5 mm – 2 mm (%) and lower content of soil aggregates < 0.25 mm (Table 4) followed by Onigambari Forest reserve (Table 3) and Osun grove (Table 1 and 2) respectively. High values of mean weight diameter indicate the dominance of less erodible and large aggregates of the soil (Piccolo *et al*., 2005). The content of WSA's decreased as the soil depth increased; this may be due to the excess litter on the topsoil; the organic matter content as well as good water and air conditions of the soil which contributed to the formation of large aggregates as observed by Tisdall and Oades (1982) and Xiao *et al*. (2008). The higher structural stability and erosion resistance observed at area J4 may be primarily due to little disturbances. Area J4 also exhibited higher levels of vegetative cover with a considerable amount of returned biomass, while Onigambari had fewer soil organic matter sources with disrupted soil structure due to excess logging, picking, and taungya farming activities observed in the area. Onigambari and Osun groves were prone to erosion especially when they suffered strong rainfall splash due to low surface vegetation coverage, and high slope gradient consequently leading to aggregates dispersed into small ones and decomposition of unstable organic carbon, which may result in a substantial decline in macroaggregates and organic carbon content (Gabarrón-Galeote *et al*., 2013).

There was a significant difference in the saturated hydraulic conductivity both under teak and Gmelina plantation along toposequence at Onigambari and Osun grove (Table 5). But at area J4, upper slope subsurface soil under Gmelina plantation and lower slope surface soil were superior to other slope segments meanwhile, middle slope subsurface soil and upper slope surface soil under teak plantation were significantly different from other slope positions (Table 5).

Table 1: Soil Water Stable Aggregate of Osun sacred Grove (Teak)

OSUN	Horizon Depth (cm)	5-2	2-1	1-0.5	0.5-0.25	<0.25	MWD
	0-30	29.88	18.28	12.64	8.72	30.48	1.52
UPP	30-145	12.60	19.40	19.20	14.60	34.20	1.02
	145-210	25.56	20.80	12.56	6.36	34.72	1.41
MDD	0-53	17.44	11.00	13.80	19.64	38.12	1.05
	53-85	20.14	21.00	11.40	7.04	40.42	1.23
LS	0-36	3.84	8.72	18.28	29.56	39.60	0.61
	36-175	1.76	3.64	7.24	18.44	68.92	0.41

Aggregate Size (mm)
MWD = Mean Weight Diameter, UPP =Upper slope, MDD = Middle Slope, LS = Lower slope.

Table 2: Soil Water Stable Aggregate at Osun Sacred Grove (Gmelina)

OSUN	Horizon Depth (cm)	5-2	2-1	1-0.5	0.5-0.25	<0.25	MWD
	0-26	1.00	5.60	14.80	31.60	47.00	0.47
UPP	26-83	2.48	13.68	0.60	15.76	67.48	0.52
	83-147	52.12	11.36	9.36	8.28	18.88	2.14
	147-210	5.20	13.80	19.20	17.76	44.04	0.71
MDD	0-28	4.48	8.28	21.44	20.56	45.24	0.63
	28-72	36.12	11.40	9.80	13.72	28.96	1.63
	72-206	23.72	20.04	10.28	7.52	38.44	1.03
LS	0-41	3.12	10.72	21.84	21.76	42.56	0.62
	41-137	2.84	12.40	15.88	15.76	53.12	0.60
	137-188	12.20	15.44	26.24	1.76	44.36	0.97

Aggregate Size (mm)
MWD = Mean Weight Diameter, UPP =Upper slope, MDD = Middle Slope, LS = Lower slope.

Table 3: Soil Water Stable Aggregate in Onigambari (Teak and Gmelina)

	Horizon Depth (cm)	5-2	2-1	1-0.5	0.5-0.25	<0.25	MWD
Teak	0-45	3.20	13.78	25.96	26.20	30.86	0.69
UPP	45-85	32.80	13.30	17.78	12.40	23.72	1.59
	85-150	53.70	12.40	11.00	9.20	13.70	2.22
MDD	0-30	12.20	13.60	17.92	17.00	39.28	0.93
	30-60	43.90	8.98	8.00	5.90	33.27	1.84
LS	0-50	5.38	9.40	18.60	26.52	40.10	0.67
	50-97	50.38	14.00	15.40	23.60	3.38	2.19
	97-150	5.40	9.00	16.50	14.20	54.90	0.64
Gmelina							
UPP	0-30	2.18	10.40	22.60	32.80	32.02	0.60
MDD	0-35	34.20	26.00	17.96	19.40	2.44	1.80
	35-80	45.20	14.98	15.78	10.80	13.24	1.99
LS	0-22	10.20	12.80	23.00	24.40	29.60	0.89
	22-90	59.60	30.42	13.56	6.40	9.98	2.69
	90-110	24.02	16.60	18.60	12.30	28.48	1.35

MWD = Mean Weight Diameter, UPP =Upper slope, MDD = Middle Slope, LS = Lower slope.

Table 4: Soil Water Stable Aggregate in Omo Forest Reserve, Area J4 (Teak and Gmelina)

OFR Area J4	Horizon Depth (cm)	5-2	2-1	1-0.5	0.5-0.25	<0.25	MWD
Teak	0-40	25.72	26.28	18.60	14.56	14.84	1.53
UPP	40-155	15.4	36.32	19.92	9.52	18.84	1.32
MD	0-35	29.48	25.20	20.92	14.32	10.08	1.65
	35-150	20.64	20.64	12.52	8.72	37.48	1.25
LS	0-40	29.44	26.64	19.92	10.96	13.04	1.65
	40-120	30.12	28.36	13.00	15.44	13.08	1.67
Gmelina	0-36	43.36	18.08	11.88	8.72	17.96	1.96
UPP	36-130	43.64	19.64	5.64	5.60	25.48	1.95
MD	0-27	35.08	16.40	4.68	2.56	41.28	1.62
	27-101	37.84	21.28	10.68	7.60	22.60	1.81
	101-140	24.24	23.92	14.40	9.96	27.48	1.42
LS	0-58	20.64	15.76	16.44	13.60	33.56	1.22
	58-170	15.44	13.00	14.20	16.60	40.76	1.01

OFR= Omo forest reserve, MWD = Mean Weight Diameter, UPP =Upper slope, MDD = Middle Slope, LS = Lower slope

Table 5: Effect of soil-forming factors on Soil hydraulic conductivity (cm hr-1)

Vegetation		Gmelina		Teak	
Location	Topography	Endopedon	epipedon	endopedon	epipedon
OFR	LOWER	1.515ab	2.635a	0.095c	3.695b
	MIDDLE	0.54b	1.135b	2.365a	1.215c
	UPPER	2.885a	0.895c	0.745b	5.995a
OGB	LOWER	0.905ns	0.785ns	0.61ns	0.765ns
	MIDDLE	1.605ns	0.685ns	1.085ns	1.395ns
	UPPER	0.755ns	0.985ns	0.765ns	1.265ns
OGR	LOWER	0.665ns	0.505ns	1.085ns	1.235ns
	MIDDLE	0.435ns	0.435ns	0.945ns	1.175ns
	UPPER	0.4ns	1.245ns	0.84ns	1.565ns
	SED = 0.43				

OFR= Omo forest reserve, OGB= Onigambari forest reserve, OGR= Osun sacred reserve
Mean with the same letter(s) along the column are not significantly different
Ns = Not significant

4.0. Conclusion and Recommendation

It was observed that area J4 had a higher quantity of soil aggregates within 5 mm – 2 mm (%) and a lower quantity of soil aggregates < 0.25 mm followed by Onigambari forest reserve and then Osun sacred grove.

The structural stability and erosion resistance of the soil in area J4 were higher than those of the soil in the Onigambari and Osun sacred grove. Onigambari and Osun sacred groves were prone to erosion when they suffered strong rainfall splash due to low surface vegetation coverage and slope gradient. Therefore, Practices that keep the soil covered physically and protect it from erosive forces that disrupt aggregation, and also building organic matter should be adopted. Agronomic practices that increase soil organic matters, and consequently biological activity, improve aggregate stability should be adopted for sustainable afforestation practices in the studied forest reserves.

Re-afforestation, regeneration, and improved fallow system are measures that could improve soil tremendously in terms of organic matter formation and therefore, should be adopted.

Declaration of Interest: None

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