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Soil organic matter and soil structural stability under different landuses in Koupendri catchment, Benin Republic

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ABSTRACT

Knowledge of contribution of land use to sustenance of soil organic matter (SOM) and soil structural stability is crucial to management of tropical soils for optimization of ecosystem services. The study evaluated SOM and soil structural stability in maize-sorghum (MS), fallow shrub land (FL) and rice field (RF) in Koupendri catchment, Benin Republic from which representative composite soil samples were collected at 0 – 20 cm depth and assessed. The SOM was highest for MS land use and significantly differed by 61 and 74% compared to RF and FL land uses. The indices for soil structural stability significantly ($p<0.05$) varied across the land uses except for 0.5–1 mm aggregate sizes and dry aggregate stability (AS_d). Overall, the MS land use recorded greatest soil structural stability than fallow shrub land and rice field. While MS may be considered more useful strategy for contributing greater SOM and higher soil structural stability in the catchment, burning the residues in the rice field and the fallow shrub land use is highly discouraged.

1.0 Introduction

Soil organic matter (SOM) has serious impact on soil quality and is also linked to the sustainability of the agricultural systems (Lal, 2010) with respect to sustained fertility and productivity (Nwite and Okolo, 2017). Most recently, Edmundo and Eduardo (2022) highlighted that SOM affected the soil nutrients' amount and availability, and contributed important nutrient elements such as N usually deficient in most soils of sub-Saharan Africa including Benin Republic. Furthermore, SOM enhances the solubility of several nutrients including P, S, K, Ca and Mg, and alters the acidity and alkalinity of the soil to a neutral state. The increased solubility of nutrient elements in fragile soils of African sub-region significantly enhances soil quality (Lal, 2010). The SOM improves the functionality of soils (Edmundo and Eduardo, 2022) through provision of colloids which have high sorption capacity (Asadu and Akamigbo, 1990). In addition, the presence of SOM in soil can stimulate positive effects that improves soil physical fertility (Blair et al., 2006) and its ecosystem services. The aggregate effects of SOM as summarized by Page et al. (2020) includes soil structure improvement, structural stability, soil strength, hydraulic conductivity, pore size distribution, water retention and higher nutrients sorption. The SOM concentration to a large extent depends on the local environmental conditions, but also strongly influenced by the soil use or management practices (Laban et al., 2018). For these reasons, prevailing land use can profoundly decide the amount of SOM available in soil. The amount and nature of SOM can also determine the direction, quality and quantity of flow of nutrients (Okebalama et al., 2017) and also microbiological activities (Edmundo and Eduardo, 2022) which can affect soil structural stabilization.

Soil structural stability is an important index for assessing nutrients sorption-desorption characteristics, cohesiveness and strength of soil and its fertility status. It controls many aspects of processes taking place in the soil which determine its health and function, conservation, and gives insight for mitigation of potential hazards, management strategies and provision of general ecosystem services. Assessment of soil structural stability indices and/or their distribution in the sub-region is needed as a guide for effective soil resources allocation and management for sustainable use. Generally, the SOM performs crucial role towards the build-up of soil structure, aggregation and stability of aggregates (Li et al., 2019). In the same vein, the aggregate formation processes including strength or stability of aggregates depend on such factors as shrink-swell processes, and the activities of living organisms (Laban et al.,2018) as well as clay content (Asadu & Akamigbo, 1990) with OM exudates playing a crucial role (Horn & Smucker, 2005). Arising from the perspective of soil management practices in agriculture, the conservation, and gains in SOM is pivotal to maintain or enhance the stability of aggregates to avoid soil losses either by erosion or surface seals (Edmundo and Eduardo, 2022). The arrangement of aggregates in soil matrix affects the pore size characteristics, retention and transmission of water, nutrients availability and air capacity of soil (Neira et al., 2020). The close link of two important parameters of porosity and water retention to the size distribution and number of pores, and the specific surface area contributing to more healthy function (Edmundo & Eduardo, 2022) of soil. Pikful and Allmarus (1986) studied different soil management practices with respect to aggregate stability and concluded that improving SOM through addition of organic manure improved the macro pores which retained water at a lower energy state. Some of the effects of SOM on soil structure identified by Hazma and Anderson (2005) include but not limited to flocculation of mineral particles as well as changes in mechanical resistance of the soil aggregates. These effects influenced the variations in the C/N ratio of SOM, type of soil and environmental conditions which depend on management practices (Edmundo and Eduardo, 2022). In all, SOM enhances the size and stability of aggregates and hence soil macroporosity, air propensity, water retention while decreasing soil compaction. The quality of soil structural stability and aggregate distribution is also important in nutrients sorption-desorption which influence its functions. Soil organic matter buffers soil functions and moderates its fluctuation with respect to pH regimes (Adeleke et al.,2017), and this enhances its fertility status.

Land use as agricultural related activities have serious impact on SOM as well as soil structural stability. In recent years, different soil management strategies such as crop rotation, fallow and conservation tillage were assessed in order to make agricultural production systems more sustainable (Deyanira Lobo et al., 2022). The practice of crop rotation has demonstrated some positive impacts towards high levels of SOM maintenance especially when legumes are included in the rotation (Deyanira Lobo *et al.*, 2022). However, the SOM accumulation rate in crop rotation involving legumes varied with soil characteristics such as structure, texture, mineralogy, and prevailing climatic conditions (Deyanira Lobo et al., 2022). In a study involving maize-cotton and maize-bean rotations, Espinoza et al.(2007) noted that the improvement in SOM observed were linked to the quality and quantity of plant residues returned to the soil but independent of the tillage system used. Lopez et al. (2006) reported general positive effect on soil properties including aggregation and structural stability in a study of sorghum-pigeon pea rotation. Laura and Jodi (2016) has reported the impact of different soil management practices on the quality and quantity of SOM. Greatest losses of SOM between 30 – 60% were associated with unsustainable soil management practices engaged under natural farming system (Anikwe, 2015). Some authors (Anikwe, 2015; Laura and Jodi, 2016) documented negative impacts of poor soil management practices to include increase of soil degradation, biomass or diversity loss, nutrients depletion and physical properties deterioration.

Due to vulnerable environmental condition resulting from global climate crisis and other emerging trends, emphasis has been intensified on studies involving land use impact on SOM (Amusan et al., 2011) and their influence on soil quality such as soil structural stability. Land use is common to farmers in Africa as well as the sub-region and seem to define sustainability of agricultural ecosystem. More stable ecosystem with healthy soil functions was obtained under fallow and other sustainable soil use and management practices (Marquez et al., 2019). Besides, the rising demographic pressure in the world and sub-Saharan region (Ogunkunle and Chude, 2022) has led to more interest in researches on land use dynamics as it decides resource allocation (Anikwe, 2010; Onweremadu et al., 2007) for different uses.

There is widespread soil degradation in Sub-Saharan Africa including Benin Republic resulting to poor ecosystem services due to land misuse and unsustainable soil management practices. This inappropriate use of soil resources have great impacts on SOM as well as soil structural stability and diminish healthy function including sustainable use of soil ecosystem. Moreover, structural stability and SOM are suitable indicators for monitoring and assessing land use dynamics in an ecosystem (Ayoubi et al., 2011). Additionally, it has been noted that soils respond differently to management systems which is dependent on inherent properties such as SOM and structural stability

(Andrews et al., 2004). More importantly, factors such as texture can largely influence SOM and hence structural stabilization. To this extent, Rabbi et al. (2014) emphasized on improved soil management practices which would ensure high organic matter input in soil. Adoption of sustainable soil management practices and appropriate land utilization are important for improving SOM pool (Lal, 2021). Soil organic matter (SOM) is pivotal for soil physical, chemical and biological fertility as well as overall soil quality (Hobley et al., 2015). Studies on land use management options and their effects on SOM content did not give attention to maize-sorghum and rice field practices or addressed their impacts on soil structural stability. Yet, these management options are widespread in tropical Africa. Moreso, aggregate distribution and stability are critical tool for predicting hazards as well as their mitigation. Due to the important role of SOM and soil structural stability on soil healthy function and support to optimal provision of sustained ecosystem services, empirical data on them is paramount and indispensable. Even though, authors (Okolo et al., 2020); carried out investigations on soil management practices and noted their impacts on SOM but with little attention on soil structural stability while dry aggregate stability (Okebalama &Marschner, 2022) was grossly under reported.

Besides, studies on land use change effect, which have emphasized SOM and soil structural stability under land use alternatives need review and validation due to extreme climate variations and differences due to soil types and site specificity. For example, Ćirić et al. (2012) reported non-significant impact of land use on macro-aggregates whereas Li et al. (2019) noted significant effect of land uses on macro aggregates.

In spite of all studies carried out on land use dynamics on SOM and soil structural stability, information is not yet sufficient for policy decision and planning in Africa and sub-Saharan region, and as a result, more research is proposed (Anikwe, 2010). Also, the emerging ecological trend in Africa presents a case for periodic evaluation and quantification of SOM on structural stability (Cantón et al., 2009) of our soil resources. Furthermore, improved and updated database would increase more confidence in appropriation and management of soil resources for greater optimization. The objective of this study was to (i) assess the effect different land uses of maize-sorghum (MS), rice field (RF), and fallow shrub land (FL) practices on SOM and soil structural stability.

2.0. Materials and Methods

2.1. Site characteristics

Koupendri catchment of northwest of Benin Republic is located at Totanga which tends to stretch from latitudes $10^{\circ}44\ ^{/}$Nto $10^{\circ}46\ ^{/}$N and longitudes $1^{\circ}08\ ^{/}$E to $1^{\circ}11\ ^{/}$E as shown (Figure 1). The catchment is characterized by flat terrain with few local hill slopes which influence its hydrology. The area is described as tropical humid climate with unimodal rainfall pattern that commences from June to October with peak rainfall period being observed in September. The mean annual rainfall is 950 mm while average temperature is 37.5 ^{o}C. The relative humidity ranges from 25 to 55% (Barry *et al.*, 2005) for dry and rainy seasons. The maize-sorghum land use is commonly practiced in the area with the one considered having lasted for more than 20 years. Animals gain access to MS field after harvests. The rice field has been under continuous cultivation for 20 years but residues are usually burnt. Fallow shrub land has been under fallow for 25 years but is usually burnt during dry season. The common vegetations are trees and shrubs.

Soil samples were collected (0 – 20 cm) from the three selected land use types of maize-sorghum (MS), rice field (RF) and fallow shrubland (FL) which are common land management practices in northwest, Benin Republic. These land uses are shown in figure 2 below. Top soil between 0 – 20 cm was considered because it is the plough layer and effective rooting depth for most legumes and cereals. Initial soil samples were collected at ten (10) different sampling points in each of the three land uses using core samplers of 7 cm x 5 cm in dimension and soil auger. This gave thirty (30) core samples and 30 auger samples collected from the three land use types and processed for baseline investigation. Similarly, soil samples were randomly and carefully collected in block form from the respective three land uses for determinations of soil structural stability indices and soil organic carbon (SOC). In each of the land uses, a maximum of 30 sampling points were selected and sampled with true representation of each location ensured by sampling in triplicates within 0.5 m radius of the sampling point and composited to give a total of ninety (90) soil samples. These samples were labelled properly and carefully taken to the laboratory for analysis. The core (undisturbed) samples were used to assess bulk density and saturated hydraulic conductivity. The composited soil samples were dried and sieved with 2 mm sieve and used to determine SOC, wet and dry aggregate stability indices, N, P, pH and particle size distribution. Laboratory processing was by standard analytical methods as described below

2.0. Laboratory determinations

The laboratory analysis was conducted at the National Institute of Agricultural Research Laboratory of Benin Republic. Organic carbon was determined using Nelson & Sommer, (1982) procedure. The organic carbon content was later converted to organic matter by multiplying with a factor of 1.724.

Soil pH was determined in 1:2.5 soil and water solution and values read (Mclean, 1982) procedure. Total nitrogen (Bremmer, 1996), available phosphorus-Bray-2 (Olsen & Sommers, 1982) and cation exchange capacity (Mba, 2004). Bulk density and hydraulic conductivity were respectively determined (Obi, 2000) procedure. Particle size distribution analysis was determined using Gee & Bauder (1986) method for sand, silt and clay fractions. Texture was obtained with textural triangle. The size distribution of water and dry stable aggregates were respectively determined by the wet and mechanical sieving methods (Kemper & Rosenau, 1986) and expressed as mean weight diameter (MWD). In both methods, 25 g of the air-dried soil sample retained on 2 mm sieve was put on the topmost of the nest of sieves of 2, 1, 0.5 and 0.25 mm. For water stable aggregates (WSA), the content was soaked initially for 5 minutes to prevent slaking and thereafter oscillated vertically in water for 5 minutes at the rate of 30 oscillations per minute with an amplitude of 4 cm. Soil aggregates left on each sieve were oven dried at 105 ^oC for 24 hours, weighed and calculated as proportion of the initial soil weight. In the case of dry stable aggregates (DSA), the content was shaken mechanically. The percentage by weight of aggregates in each fraction as proportion of the initial soil weight (25 g) after mechanical shaking was calculated and recorded. The aggregate stability (AS) as percent of water-stable aggregates (WSA) > 0.5 mm on each sieve was determined thus:

$$AS = \frac{(Mwsa - MS)}{(Mt - MS)} \times 100 \qquad (2)$$

where

Mwsa = mass of water stable aggregates > 0.5 mm plus sand (g)

MS = mass of the sand fraction alone (g)

Mt = total mass of the sieved soil (g)

The MWD for the DSA and WSA were calculated based on the equation proposed by Chaney & Swift (1984) as:

$$MWD = \sum x_i \, w_i \qquad (3)$$

Where x_i = the mean diameter of any particle size range of aggregates separated by sieving, and w_i = the weight of aggregates in that size range as a fraction of the total initial dry weight (25 g) of soil used.

2.1. Statistical analysis

The data obtained for soil organic matter and soil structural stability indices were subjected to analysis of variance (ANOVA) using GENSTAT Discovery Software, Edition 4. Significant differences for means were compared using the Fisher's least significant difference (F-LSD) procedure as described by Obi (2002). Differences were accepted at 5% probability level. Soil organic matter and stability indices were further evaluated using coefficient of variation (CV) to measure variability of the soil data

3.0. Results and Discussion

3.1. Some baseline physicochemical properties of soil under different land uses

The physicochemical properties of the soil showed that the soils were mostly loam and sandy loam in texture with high silt content ranging from 400 g/kg to 460 g/kg (Table 1). Generally, the permeability of the soil was low and ranged from 8.83 cm/hr to 13.72 cm/hr. The pH of the soils were slightly acidic whereas available phosphorus and nitrogen content of the soils were very low. The CEC showed moderate soil fertility whereas bulk density ranged from 1.5 g/cm^3 to 1.6 g/cm^{3}indicating that the soils were less compacted

Table 1: Some physicochemical properties of soil under different land uses

Land use	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	Texture	BD (g/cm^3)	Ksat (cm/hr)	pH	P (mg/kg)	TN (%)	CEC (cmol/kg)
MS	520±21.0	400±12.1	80±5.2	SL	1.55±0.01	10.15±0.11	5.8±0.02	2.0±0.02	0.05±0.01	8.0±0.15
RF	440±15.2	460±14.3	100±7.9	L	1.63±0.02	8.83±0.13	6.6±0.05	1.0±0.01	0.06±0.01	7.84±0.11
FL	430±10.5	450±15.1	108±6.6	L	1.49±0.01	13.72±0.25	6.0±0.04	3.0±0.05	0.08±0.02	7.64±0.21

MS = maize-sorghum, RF = rice field, FL = fallow shrubland, SL = sandy loam, L = loam, BD= bulk density, Ksat = saturated hydraulic conductivity, P = available phosphorus, TN = total nitrogen, CEC = cation exchange capacity

3.2. *Soil organic matter (SOM) content as affected by different land use*

The SOM as shown in Figure 3 indicates significant ($p < 0.05$) differences in maize-sorghum (MS) land use and other soil management alternatives. Highest SOM content of 26.1 g/kg which could be rated high (Enwezor *et al.*, 1989) was observed for maize-sorghum (MS) land use compared to low values of 15 and 16.2 g/kg respectively recorded for fallow shrub land (FL) and rice-field (RF) management options. This translates to respective 61 and 74% significant increments of SOM for MS land use relative to other land uses. This implies that MS utilization contributed significantly almost twice SOM to the soil in relation to the other land uses. Nevertheless, there was no significant difference in SOM between fallow land and rice field management uses for the period.

3.3. *Soil structural stability indices and aggregate sizes distribution*

The effect of land uses on soil structural stability indices and aggregates size distribution are shown in Tables 2 and 3 below. Significant ($P<0.05$) high wet aggregate stability (AS_W) of 37.7% with moderate coefficient of variation (CV) of 32.0% was obtained for MS which represents 29 and 70% significant improvements for the measured index when compared to corresponding lower values of 26.8 and 11.3% recorded for alternative management uses (Table 2). Similarly, AS_w of FL differed significantly ($p<0.05$) by 58% compared to RF. The dry aggregate stability (AS_d) did not differ significantly ($p<0.05$) across the land use but the highest value of 54.5% (CV>37.6%) was recorded for MS land use (Table 3). This was followed by 53.3% observed for FLwhich is 12% increment relative to the value of 46.9% obtained for RF management option. In addition, significant ($p<0.05$) differences in the mean weight diameter of dry stable aggregates (MWD_d) and water stable aggregates (MWD_w) were observed.

The MWD_d of 2.10 mm with moderate CV of 36.1%, and MWD_w of 1.70 mm with corresponding CV of 31.1% were respectively obtained for MS land use as against the respective values of 0.81 and 0.41 mm for fallow land use as well as 1.69 and 1.47 mm for rice field. These account for 20 and 30% as well as 53 and 76% significant increments for the stability indices in MS land use when compared to fallow and rice field land uses respectively.

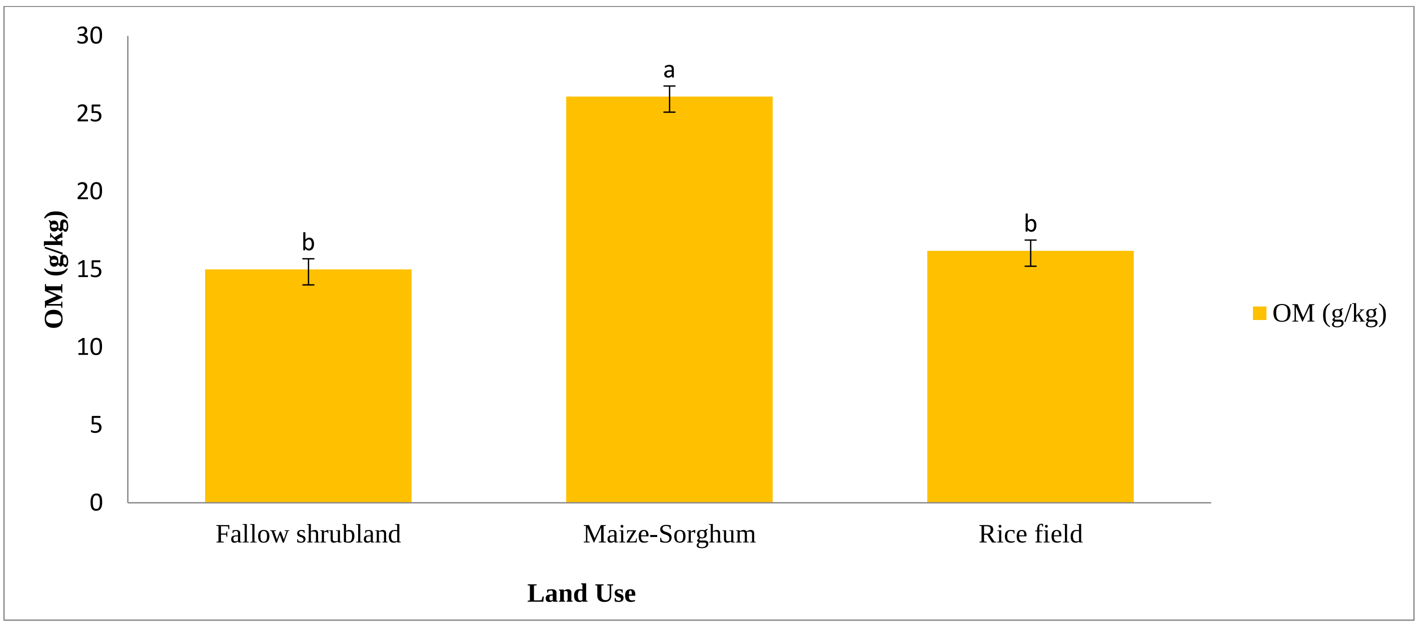

Figure 3: Soil organic matter contents in three different land use types in Koupendri Catchment Bars with different letters are significantly different at $P < 0.05$ across the different land uses while bars with similar letters are not significantly different.

The results also showed that significant ($p<0.05$) aggregate size > 2 mm values of 14.09 mm for WSA with high CV of 43.8%, and 10.98 mm for DSA with high CV of 45.0% were recorded respectively for MS land use, when contrasted with the respective lower values of 10.68 and 8.95 mm obtained for fallow land use as well as 3.97 and 1.26 mm obtained for rice field. These respectively represent 24 and 39% as well as 34 and 89% significant improvements for the aggregate size for MS with respect to those of fallow land use and rice field (Table 2). Moreso, FL had 68 and 16% significantly higher aggregate size > 2 mm compared to RF option for respective WSA and DSA. However, significant ($p<0.05$) highest values of WSA (2.16 mm) and DSA (3.00 mm) for aggregate size between 1–2 mm was obtained under FL . These gave 6 and 5% as well as 25 and 2% significant increments for the aggregate size distribution for FL in comparison to for MS and RF land uses respectively. For aggregate size between 0.5 – 1 mm, there was generally no significant ($p<0.05$) differences amongst the land use options for both WSA and DSA. The results also showed that significant ($p<0.05$) highest values of 2.63 mm (CV < 27.2%) for aggregate size between 0.25 – 0.5 mm was obtained under RF land use for WSA compared to other uses. This represents 31 and 38% increment for the 0.25 – 0.5 mm aggregate size relative to other land use options.

However, significant ($p<0.05$) highest values of 0.82 mm (CV > 45.6%) for aggregate size between 0.25 – 0.5 mm was obtained under MS land use for DSA compared to other land use options. The results showed that aggregate size < 0.25 mm differed significantly ($p<0.05$) across the land uses with the highest values of 18.75 mm for DSA and 12.01 mm for WSA respectively obtained under RF land use. These account for 16 and 51% as well as 13 and 38% respectively higher increments of the aggregate size <0.25 mm for RF compared to other land use options.

3.4. Discussion

A healthy and optimal functioning ecosystem is expected to have high SOM to improve soil structural stability as well as determine nutrients sorption-desorption characteristics and resilience to degradation. The significantly ($p < 0.05$) higher SOM input obtained for MS land use is a positive indication that the management practice contributed more than other uses to improvement of soil. Increased SOM would encourage greater soil structural stability. This could boost recycle of nutrients and foster resilient characteristic quality on the soil. The SOM of the MS field, which significantly differed from the other land uses, could be attributed to cation exchange capacity rather than texture (Table 1). Additionally, higher SOM of MS use relative to its counterparts could also be attributed to effects of previous stalks and animal wastes from grazing animals common in the catchment. Our finding supports Okebalama et al. (2017) who reported that stalk of cereal crops such as maize and sorghum left after harvest on the field increased SOM in cultivated land to significant level more than uncultivated sandy loam soil at Nsukka, southeastern Nigeria. Similar SOM contents obtained for FL and RF land uses suggest comparable contributions of SOM by the management uses. Similar loamy texture and CEC recorded (Table 1) for the two land uses could have influenced comparable SOM mineralization in the soils. Texture of soil particularly has been noted (Smith et al., 1998) to relate to nutrients content and soil structural stability (Obi, 2000). Moderate to low SOM contents (Enwezor et al.,1989) of the soils of FL and RF could further be attributed to occasional bush burning commonly experienced in the study area. Residue burning escalates decomposition and volatilization of nutrients, which result to reduction of SOM (Habtamu et al., 2019). Our result of low SOM in FL and RF land uses is comparable to 30 – 60% losses reported for natural farming system (Anikwe, 2015).

Table 2: Measured (Wet) structural stability indices and aggregate sizes distribution under different land uses

Land use	> 2 mm	1-2 mm	0.5-1 mm	0.25-0.5 mm	< 0.25 mm	AS (%)	MWD mm
			Water-stable aggregate size distribution (WSA)				
FL	3.97±0.02	2.16±0.01	1.37±0.01	1.81±0.02	15.69±0.22	26.8±0.44	0.81±0.01
MS	10.98±0.12	2.03±0.015	1.18±0.005	1.63±0.02	9.19±0.18	37.7±0.85	1.71±0.02
RF	1.26±0.01	1.04±0.012	1.32±0.006	2.63±0.05	18.75±0.28	11.3±0.25	0.41±0.005
CV %	45.0	34.8	31.6	27.2	15.6	32.0	31.1
F-$LSD_{0.05}$	**1.25**	**0.31**	**NS**	**0.28**	**1.17**	**4.15**	**0.16**

AS = aggregate stability, MWD = mean weight diameter, FL = fallow shrobland, MS = maize-sorghum, RF = rice field, CV = coefficient of variation, NS = non-significant.

Table 3: Measured (Dry) structural stability indices and aggregate sizes distribution under different land uses

Land use	> 2 mm	1-2 mm	0.5-1 mm	0.25-0.5 mm	< 0.25 mm	AS (%)	MWD mm
			Dry-stable aggregate size distribution (DSA)				
FL	10.68±0.19	3.00±0.03	0.27±0.001	0.55±0.012	10.51±0.15	53.3±1.25	1.69±0.10
MS	14.09±0.28	2.25±0.01	0.34±0.002	0.82±0.026	7.50±0.11	54.5±1.11	2.10±0.12
RF	8.95±0.11	2.95±0.02	0.37±0.018	0.72±0.018	12.01±0.21	46.9±1.24	1.47±0.09
CV %	43.8	28.8	54.3	45.6	45.4	37.6	36.1
F-$LSD_{0.05}$	**2.53**	**0.40**	**NS**	**0.16**	**2.33**	**NS**	**0.32**

AS = aggregate stability, MWD = mean weight diameter, FL = fallow shrobland, MS = maize-sorghum, RF = rice field, CV = coefficient of variation, NS = non-significant.

Aggregate stability (AS) is used to express degree of soil structural stability (Obi, 2000). Well structural stabilized soil has the capacity to retain and recycle nutrients as well as improve moisture retention and transmission properties of soil, promote aeration, root proliferation and enhance inflow and/or influx of materials to optimize ecosystem services, thus increasing soil fertility status and productivity. The high AS_W value of 37.7% obtained for MS land use compared to other land use options indicates strong soil structural stability. This could be attributed to the high level of SOM content in the soil when compared to other uses (Figure 1). Apart from the fact that the soil under MS land use would be more resistant to destabilization (Obi, 2000), it would be more stable and less erodible. The higher SOM content of soil under MS would reduce wettability (Kroll et al., 2013) and render it more stable to mitigate hazards of degradation more than the alternatives land use options. It may be inferred that SOM is critical for mechanical soil structural stabilization; thus, more SOM could be required for the land uses to achieve significant improvement in soil structural stability. This observation corroborated the findings of Kroll et al. (2013) that Soil organic matter have strong influence on the mechanical strength of aggregates which in turn helps to reduce or withstand disaggregation and erodibility. The FL land use considering the value for its AS_w ranks next in structural stability compared to RF option. Other soil properties that could influence soil aggregation in the study area includes but not limited to bulk density, clay contents etc. For instance Obi (2000) noted that lower soil bulk density increases contact surfaces for more interaction and, therefore encourage aggregation. Similarly, clay content promotes soil structural stability (Laban et al., 2018).

Mean weight diameter (MWD) is a weighted average of the particle sizes and an index for soil structural stability. The significantly higher MWD_w values obtained for MS land use compared to FL and RF land uses indicates higher soil structural stability. This implies that MS land use increased soil structural stability more than the other two land use types. Besides SOM content of the soil, it has been reported that fungal associations were common with maize-sorghum cereal crops and stimulate structural stabilization of soils. The MWD_w for FL which was slightly different from RF land use indicates that land use types with comparable SOM could vary in soil structural stability. This variation is a reflection of AS_w (Table 2) but not clay content (Table 1). Poor soil structural stability for RF could be linked to puddling common in rice cultivation which impedes structural stability compared to a more stable fallow ecosystem (Anikwe, 2015). This implies that RF could be more prone to soil structural degradation. A similar trend of the significantly highest value of MWD_w for MS was observed for MWD_d, suggesting that the MS land use promotes soil structural stability for either condition. Significant improvement in the soil structural stability for FL land use relative to RF land use is an indication of poor management practice due to the destabilization action of traffic from human and animals (Oades, 1993) which reduce structural stability in RF land use. Low soil structural stability of RF could also be attributed to low SOM content in disturbed soils (Okebalama et al., 2017).

Generally, the values for MWD_d for the various land uses were higher compared to those of MWD_w implying more stabilization. Our finding tends to differ from mechanical disaggregation of aggregates due to the burning effect (Ferreira et al., 2010) and low soil structural stability arising from a decline in SOM (Are et al., 2009). The significant impact of land use on AS_w and MWD_w was noted in Ćirić et al., *(*2012) who failed to report the critical nature of AS_d to soil structural stability. A significantly higher aggregate size > 2 mm was recorded for MS land use for WSA than for other land uses. This suggests that the MS land use option more than others could increase macro-aggregate stability.

This could be attributed to the high level of SOM found in MS land use. Li et al. (2019) reported a similar significant impact of land use on macro-aggregate stability. However, the high aggregate > 2 mm obtained for FL land use relative to the RF land use option is an indication that macro aggregate > 2 mm is dependent not only on SOM content but also on land use or soil management practice. Generally, the highest values of aggregate size > 2 mm observed for MS and FL land uses respectively are also in tandem with their respective highest values for AS_w compared to the RF land use option (Table 2). Similarly, the highest aggregate size > 2 mm for DSA was obtained under MS land use and followed by FL land use while the least value was obtained under RF land use (Table 3). In addition to other factors, the result suggests differences in the capacities of soils under different land use or soil management to encourage and promote macro-aggregate size stability > 2 mm. Macro-aggregates have advantage of increased ecosystem services such as water transmission, aeration, root biomass diversity and microbial activities. Above all, such aggregate would be less erodible. However, the macroaggregates may face the problem of unsustainability resulting from the likely risk of its collapse due to microbial action (Mandiola et al., 2011). Our observation of high macro-aggregate size > 2 mm for FL compared to what obtains under RF tends to support the findings of other researchers (Zheng et al., 2018) who had previously reported that low value of SOM results to the formation low and unstable macro-aggregates which breakdown, deteriorate and loose vital soil functions. The high value of aggregates 1 – 2 mm obtained under fallow land use relative to MS and RF land uses for WSA showed that fallow system as a soil management practice could increase macro aggregates of such size. This result corroborate the findings of Laura & Jodi (2016) that natural system facilitates macro-aggregate stability. However, land cultivation could lead to the breakdown of these macro aggregates despite high level of SOM as in the case of MS land use and lead to the decline in soil structural stability. Such decline in soil structural stability result to reduction in vital ecosystem services and lead to loss of productivity (Mbagwu, 1992). Essentially, RF had the lowest aggregate size 1 – 2 mm possibly indicating instability occasioned by anthropogenic activities common in rice fields (Oades, 1993; Six et al., 2000). Fallow shrub land maintained significant higher aggregates 1 – 2 mm for DSA when compared to other land uses. In this, we infer that fallow land could be superior to others in increasing the dry macro-aggregate size between 1 – 2 mm in the study area. However, the DSA as against its corresponding counterpart for WSA was significantly higher for RF land use than for MS land use. This entails that sustenance of aggregate size 1- 2 mm depends on soil condition and not management option. Our finding disagrees with earlier report of Ćirić et al. (2012) that soil management options failed to have significant influence on dry macro-aggregate size between 1 – 2 mm.

In general, the different soil managements or land uses did not significantly impact on aggregate size 0.5 – 1 mm for WSA and DSA. Although, the aggregates varied among the different land uses with the highest values obtained at FL and RF land uses, but were generally low. This implies that aggregate size 0.5 – 1 mm is critical to soil structural stability and cannot be salvaged by SOM. Such low mass aggregate size fraction could impose problems on soil management for structural stability and limit ecosystem services. Compared to other macro aggregate fractions, 0.5 – 1 mm aggregate seems to be the lowest, thus indicating that it contributed minimally to soil structural stability. Zheng et al. (2018) made similar observation for low mass aggregate size fraction between 0.5 – 1 mm in their studies. The significant high value for 0.25 – 0.5 mm aggregate size observed for RF land use relative to other land uses for WSA suggests that the RF land use made important contribution to soil micro-aggregates more than other land uses. The similar values of 0.25 – 0.5 mm for MS and FL land uses imply that the two management practices are comparable and can form low micro aggregate size fractions irrespective of their SOM contents. Instability caused by human trafficking during farming activities in MS land use could impede SOM and reduce its capacity to form stable macro aggregate. This was corroborated by Six et al. (2000) that traffic and cultivation reduced C-rich macro aggregates and increased C-depleted micro-aggregates. Even though, the aggregates decreased for DSA in all the land uses, significantly higher value for 0.25 – 0.5 mm was recorded under MS land use. This result indicates the minimal impact of the aggregate size 0.25-0.5 mm except for MS land use on soil structural stability. The dominance of low micro aggregate size 0.25 – 0.5 mm especially for RF land use signals soil management problems for sustainable soil structural stability as it could lead to increased soil erodibility, collapse of soil structure and decline in ecosystem services. On the other hand, macro aggregates are resistant to erosive forces and therefore more stable and sustainable (Simansky et al. 2011).

The highest value of aggregate size < 0.25 mm obtained under RF land use or management for WSA which significantly differed from those of other land uses is an indication of low structural stability. It is also a reflection of lower AS_w and MWD_w (Table 2) as observed in this study. Poor soil structural stability could cause structural collapse and increase soil management problems for potential optimization (Obi, 2000). The FL land use also gave significantly higher < 0.25 mm relative to MS probably suggesting that the lower the SOM the more unsustainable the soil structural stability. Against the report of Ćirić et al. (2012) of non-significant effect of land use on aggregates < 0.25 mm, our findings indicate that land use has a significant impact on aggregate size <0.25 mm. Similarly, RF had the greatest impact on aggregate size <0.25 mm for DSA compared to other land uses. This corresponds to low soil structural stability recorded for AS_d as well as MWD_d (Table 3)

The high value of aggregates 1 – 2 mm obtained under fallow land use relative to MS and RF land uses for WSA showed that fallow system as a soil management practice could increase macro aggregates of such size. This result corroborate the findings of Laura & Jodi (2016) that natural system facilitates macro-aggregate stability. However, land cultivation could lead to the breakdown of these macro aggregates despite high level of SOM as in the case of MS land use and lead to the decline in soil structural stability. Such decline in soil structural stability result to reduction in vital ecosystem services and lead to loss of productivity (Mbagwu, 1992). Essentially, RF had the lowest aggregate size 1 – 2 mm possibly indicating instability occasioned by anthropogenic activities common in rice fields (Oades, 1993; Six et al., 2000). Fallow shrub land maintained significant higher aggregates 1 – 2 mm for DSA when compared to other land uses. In this, we infer that fallow land could be superior to others in increasing the dry macro-aggregate size between 1 – 2 mm in the study area. However, the DSA as against its corresponding counterpart for WSA was significantly higher for RF land use than for MS land use. This entails that sustenance of aggregate size 1- 2 mm depends on soil condition and not management option. Our finding disagrees with earlier report of Ćirić et al. (2012) that soil management options failed to have significant influence on dry macro-aggregate size between 1 – 2 mm.

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4.0. Conclusion

Soil organic matter and soil structural stability varied in response to the different land uses in the study area. Amongst the land uses, SOM is highly significant for the MS land use option whereas SOM for FL and RF land uses remained similar comparatively. Soil structural stability varied according to land use options, SOM and stability indices, thus indicating the need to determine the utilization type for which SOM and soil structural stability is critical for optimized ecosystem services. Generally, maize-sorghum land utilization has greater SOM and soil structural stability than the other two land uses which differ minimally. Thus, MS may be considered an important strategic practice for increasing SOM and soil structural stability. However, improvement in aggregates 0.5 – 1 mm and AS_d remain critical for soil structural stability in the catchment and similar soil. More importantly, soil texture, bulk density and CEC influence SOM and soil structural stability. Consequently, SOM content and soil structural stability could be a function of soil management option, physical and chemical composition as well as the stability indices

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