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Effect of tillage and maize-cowpea intercrop on fractal features of particle and aggregate size distribution on a tropical sandy loam soil in southwest Nigeria

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ABSTRACT

The effects of tillage and cropping pattern on soil aggregation, fractal dimensions and distribution of organic carbon fractions were studied. Treatments were no-tillage (NT), conventional tillage (CT), and four cropping patterns viz: sole maize, sole cowpea, maize-cowpea intercrops and control (no crop). Soil samples were analysed for particle size distribution (PSD); aggregation ratio (AR), mean-weight diameter (MWD) and aggregated silt+clay (ASC). Mass fractal dimension (Dm) was obtained from PSD; while fragmentation fractal dimension (Df) was obtained from aggregate sizes. Total organic carbon (TOC), free and occluded particulate organic carbon (fPOC and oPOC), were measured. Results showed that structural stability at micro-aggregate scale measured by aggregated silt + clay (ASC) was significantly ($p < 0.05$) highest for NT (4.07) than CT (1.58). The CT significantly ($P \leq 0.05$) reduced the larger aggregate fraction (5.66-2.00 mm). The difference in fractal dimensions was significantly higher with NT than control with CT. Lower difference between Dm and Df with CT represents higher degree of fragmentation of aggregates. Correlation showed significant positive linear relationships between Dm and sand ($p < 0.05$, $r = 0.627$) and negative relationship with silt and clay ($r = -0.675$). Therefore, fractal dimensions derived from aggregates sizes rather than particle size distribution reflected the impact of land management practices on fragmentation of aggregates of most tropical soils.

1.0. Introduction

Soil degradation is one of the most serious problems contributing to decline of tropical ecosystems. Tillage and types of cropping pattern are important agricultural management practices affecting the soil quality. These could result in soil degradation induced by erosion with inappropriate choice of tillage practice, and when a soil is subjected to continuous cultivation for a long period. Fragmentation caused by either tillage operations or the natural wetting/drying cycles is a process whereby a coherent body like soil breaks apart into smaller pieces (Perfect et al., 2002; Grant et al., 1995; Edwards, 1991), resulting in soil structural changes. Also, aggregate size distribution found to be a good indicator of soil structure (Filgueira et al., 1999) and soil organic carbon composition are dynamic properties influenced by land use like cropping pattern apart from tillage.

According to Ahmadi et al. (2011), several procedures have been proposed for characterizing soil aggregate distribution. The temporal variation of aggregation (Saiedi et al., 2017) and soil particle size distribution with similar soil type where fine particle size fractions are selectively removed and deposited by runoff (Xu et al., 2013) can be estimated by fractal geometry. Fractal geometry shows that natural objects have similar features such as number, mass, length, and surface area at different scales; and these features depend on the scale of measurement (Filgueira et al., 1999). These dependencies are represented by a power -law relationship between the features of the aggregates (Ahmadi et al., 2011), soil hydrologic processes (Pachepsky et al., 2008), and other properties in soils such as texture, moisture characteristic and aggregate stability (Li, and Zhang, 2000).

Fractal features are also important in quantifying soil degradation (Xu et al., 2013; Su et al., 2004) and sensitivity to tillage. Fractal dimension of soil aggregates was used by Martinez-Mena et al. (1999) as an indicator of soil erodibility. According to Filgueira et al. (1999), Rieu and Sposito (1991) proposed two fractal dimensions, i.e. mass fractal dimension (Dm) of an incompletely fragmented soil and the fractal dimension (Df) of a completely fragmented soil, to describe soil fragmentation process. According to Perrier and Bird (2002), complete fragmentation means all aggregates breakdown into primary particles. Therefore, Filgueira et al. (1999) indicated Dm to be affected by soil texture, while fragmentation fractal dimension (Df) corresponds to soil structure where lowest Df values were found in well-developed soil structure; and higher values of Df associated with lower aggregate stabilities (Xu et al, 2013). Also, the difference between mass fractal dimension and fragmentation fractal dimension indicate the degree of fragmentation (Filgueira et al. 1999); and when the difference is lower, the degree of fragmentation is higher (Filgueira et al., 1999; Perfect et al., 1997; Rieu and Sposito, 1991).

Since soil aggregate formation and its stability are linked to organic matter or its fractions (Das et al., 2014), organic carbon contents were also used to assess the treatments effect. This study therefore investigated the applicability of fractal dimensions to assess possible improvement in physical quality of a fragile tropical soil following different tillage and cropping patterns.

2.0. Materials and methods

2.1. Experimental site description

The experiment was conducted in the Teaching and Research farm of the Federal University of Agriculture, Abeokuta, Ogun State, Nigeria (Latitude 7.12° N and Longitude 3.23° E). This area is located within the transition zone of the sub-humid forest to the south and the derived savannah to the northwest. The rainfall distribution for this area is bimodal with a wet season from March to October and a dry season from November to February. The mean annual rainfall is about 1400 mm with the maximum in July. The mean monthly temperature range varies between 28°C and 32°C. The soil at the experimental site is Oxic Paleustalf, and it is well drained sandy loam on the surface with gravelly sandy clay loam on the sub-surface (Adesodun et al., 2015). Selected properties of the soil prior to the establishment of the experiment are shown in Table 1.

2.1. Experimental treatment, land preparation and soil sampling

The experiment was a factorial in a Randomized Complete Block Design. The treatments were tillage types, i.e. no-tillage (NT) and conventional tillage (CT); and cropping types, i.e. sole maize, sole cowpea, maize-cowpea intercrop, and control (no crop). These treatments were replicated four times making a total of thirty two (32) plots of size 5 m by 4 m each. Under NT, no ploughing was done while the weeds were cleared manually with the use of hoe and cutlasses to ensure minimum disturbance. Under CT however, the field was ploughed once and harrowed seven days later. Improved variety of maize used was 2004-TZE-W-POP-STR-C4, while the improved variety of cowpea used was IT07K-299-6. Soil samples were collected at the beginning of the experiment at 0-15 cm depth and also from each plot after crop harvest for laboratory analysis. The initial properties of the soil of the experimental site are presented in Table 1.

Table 1. Some initial physical and chemical properties of the soil

Soil properties	**Unit**	**Value**
Sand	%	79
Silt	%	6
Clay	%	15
Textural class	-	Sandy loam
pH	-	6.9
Organic carbon	g kg^{-1}	2.52
Total N	g kg^{-1}	1.40
Available P	mg kg^{-1}	7.51
K^{+}	c mol kg^{-1}	0.80
Ca^{++}	c mol kg^{-1}	0.19
Mg^{++}	c mol kg^{-1}	0.22
Na^{+}	C mol kg^{-1}	0.72

2.2. Particle and aggregate size distributions

Particle size analysis was by the hydrometer method using 50 g of air-dried soil sieved through 2 mm mesh; while aggregate size distribution was measured by wet-sieve method of Kemper and Rosenau (1986). In the aggregate size distribution procedure, 50 g of the <5.66 mm aggregates were placed on the topmost of a nest of sieve of diameters 2, 1, 0.5 and 0.25 mm. The samples were pre-soaked in distilled water for 10 min before oscillating vertically in water 20 times (along 5 cm amplitude) at the rate of 15 stokes mm-1 for 2 min. The resultant aggregates on each sieve were dried at 105°C for 24 hours and weighed; while the mass of < 0.25 mm fraction was obtained by difference between the initial sample weight and the sum of sample weights collected on the > 0.25 mm nest of sieves.

The percent water stable aggregates (%WSA) on each of the following size ranges, 5.66-2.00, 2.00-1.00, 1.00-0.50, 0.50-0.25 and < 0.25 mm were obtained as:

%WSA = (Ms - Msand/Mt - Mtsand) (1)

where, Ms is the total mass of oven-dried soil sample after wet-sieving (g), Msand the oven-dried mass of sand in that soil fraction (g), Mt the total mass of the whole soil sample (g), and Mtsand the mass of sand in the whole soil sample (g). The mean weight diameter (MWD) of wet-stable aggregates was calculated as from the %WSA data as:

$$MWD = \sum_{i=1}^{n} XiWi \quad (2)$$

where, Xi is the mean diameter of each size fraction (mm),Wi is the proportion of the total sample weight (WSA) in the corresponding size fraction after deducting the weight of stone and n is the number of size fractions. Higher values of MWD indicate the dominance of the less erodible large aggregates of the soil (Adesodun et al., 2007; Piccolo et al., 1997).

Aggregate ratio (AR) was calculated according to Singh and Benbi (2018) as:

$$AR = \frac{\%Water\ stable\ macroaggregates > 0.25\,mm}{\%Water\ stable\ aggregates < o.25\,mm} \quad (3)$$

Macro-aggregate stability was estimated by Aggregate silt + clay (ASC) from the analysis of particle size of the soil as:

Aggregate silt + clay (ASC) = (TC+TSilt) – (WDC+WDS) - - - - - (4)

Higher value of ASC indicates better soil aggregation, i.e. higher aggregate stability at microaggregate level (Adesodun and Adekonojo, 2011; Igwe and Nwokocha, 2006; Mbagwu et al., 1993).

2.3. Fractal parameter

Based on fractal models proposed by Rieu and Sposito (1991), two fractal dimensions were estimated in this study to evaluate the impact of the tillage types and cropping pattern applied on the soil physical quality. That is, mass fractal dimension (Dm) of an incompletely fragmented soil affected by texture and the fractal dimension (Df) of a completely fragmented soil which corresponds to soil structure estimated from soil aggregates by dry sieving.

The fractal dimension (D) of particle size distribution (PSD) and soil aggregate fraction of sizes 5.0 mm-2.0 mm, 2.0 mm – 1.0 mm, 1.0 mm – 0.50 mm, 0.50 mm – 0.25 mm and < 0.25 mm were then fitted into the fractal model of Tyler and Wheatcraft (1992):

M (r < Ri)/MT = (Ri/Rmax)m3-D (5)

According to Xu et al. (2013), taking the logarithm of both sides in equation (5) solves D as:

D = 3 -

where D is fractal dimension of PSD or aggregate size extracted from the slope; M is the cumulative mass of particle or aggregates of the ith size, r less than Ri; MT is the corresponding total mass; Ri is the mean particle or aggregate diameter (mm) of the ith size class; and Rmax is the mean diameter of the largest particle or aggregate. Furthermore, the difference between mass fractal dimension (Dm) and fragmentation fractal dimension (Df) according to Filgueira et al. (1999) also indicate the degree of fragmentation where lower difference represents higher degree of fragmentation.

2.4. Total organic carbon and carbon fractions

Air-dried soil samples were collected at 0-15 cm depth in each plot and pre-sieved with 2 mm sieve. Concentrations of the total organic carbon (TOC) and organic fractions such as free particulate organic carbon (fPOC), occluded particulate organic carbon (oPOC), acid-hydrolyzable organic carbon (aHOC) and non-acid hydrolysable organic carbon (nHOC) were determined from these samples. The TOC was determined by acid dichromate wet-oxidation procedure of Walkley and Black (1934) as adapted by Nelson and Sommers (1996). The particulate organic carbon fractions were determined following the procedure of Cambardella and Elliot (1992). In this procedure, 20 g of air-dried soil was weighed into a beaker and then shaken with 10 ml sodium hexa-meta phosphate (Calgon) solution. The suspension was passed through a 53 um sieve to separate out > 53 µm and < 53 µm fractions. Both the >53 µm and < 53 µm were oven-dried and then ground to <0.05 mm. One gram each of > 53 µm and < 53 µm was used for OC determination by acid-dichromate wet oxidation method presented by Nelson and Sommers (1996). The oPOC is the fraction retained on 53 um sieve while fPOC is the fraction that passes through the 53 um sieve.

The acid-hydrolyzable and non-acid hydrolyzable OC concentrations were determined by the procedure of Paul et al. (2001). In this procedure, 2 g of soil (< 2.00 mm) was mixed with 6 N HCl and allowed to react for 2 hours. The samples were later heated at 1050C for 3 hours, washed three times with distilled water and then centrifuged to remove the HCl. The residue was dried and the non-acid hydrolyzable OC was determined by acid-dichromate wet oxidation procedure of Nelson and Sommers (1996). The hydrolyzable OC concentration was calculated as the difference between TOC and non-acid hydrolyzable OC concentration.

2.5. Data analysis

Data was analysed using the general analysis of variance procedure of GenStat Release 9.2 DE (2007), and significance was reported at 5% probability level. Correlation analysis was used to determine the relationship of the fractal dimensions (Dm and Df) with particle size distribution, soil aggregate parameters and soil organic carbon.

3.0. Results and discussion

3.1. Particle size distribution

Particle size distribution of soil samples collected from the plots showed that the predominant textural component was sand which ranged from 76 % to 79 % irrespective of the treatments applied (Table 2). This was followed by clay which ranged from 14.2 % to 16.45%, while the silt contents (6.05 % to 8.55 %) were lower. The slight differences in particle-distribution Table 2) did not alter the soil textural class due to dominance of the parent material on soil texture. In this case, particle sizes could have differed slightly due to soil disturbance (Udom et al., 2018).

3.2. Aggregate distribution and stability

The results in Table 3 show that conventional tillage (CT) operation when compared with no-tillage (NT) significantly decreased the larger aggregate fraction (> 2.00 mm), while the smaller aggregate fractions (< 2.00 mm) were increased with highest aggregate proportion obtained in the micro-aggregates fraction (< 0.25 mm). Specifically, CT decreased the proportion of 5.66-2.00 mm fraction by 74 %, 65 %, 54 %, and 65 % for control, cowpea, maize and intercropped plots respectively. This trend showed that conventional tillage operation led to fragmentation of this fragile tropical soil to smaller aggregate fractions.

Table 2. Particle size distribution relative to treatments

Tillage	Cropping system	Sand (%)	Silt (%)	Clay (%)
NT	Control	77.00^{ab}	6.55^{abc}	16.45^{a}
	Sole cowpea	77.00^{ab}	7.80^{ab}	15.20^{ab}
	Sole maize	79.50^{a}	6.05^{bc}	14.45^{b}
	Maize-cowpea intercrop	79.00^{ab}	5.55^{c}	15.45^{ab}
CT	Control	76.00^{b}	8.55^{a}	15.45^{ab}
	Sole cowpea	77.50^{ab}	6.80^{abc}	15.70^{ab}
	Sole maize	78.00^{ab}	7.30^{abc}	14.70^{ab}
	Maize-cowpea intercrop	78.75^{ab}	7.05^{abc}	14.20^{b}

The stability of the soil as measured by mean-weight diameter (MWD) relative to the different tillage and cropping pattern showed higher values with NT, and significantly highest MWD (1.494 mm) observed in intercropped plots (Table 3). General soil aggregation as summarized by aggregate ratio (AR) followed the trend of the MWD; however, planted maize improved the stability of this soil over other cropping pattern while AR 1.081 mm recorded in CT was not significantly different from values for NT. Higher stability of this soil at micro-aggregate scale measured by aggregated silt + clay (ASC) was in NT, with highest values for NT (4.07) and CT (1.58) in maize-cowpea intercropped plots (Table 3). High ASC indicates better soil aggregation. This result followed the observations of Adesodun et al. (2007), Spaccini et al. (2001) and Beare et al. (1994). Adesodun et al. (2007) reported reduction in the proportion of macroaggregate fractions (> 0.25 mm) following cultivation of a rainforest and savannah agro-ecological areas; while Spaccini et al. (2001) observed reduction in the proportion of the large aggregate class (> 1.00 mm) for cultivated soils in eight Ethiopian highlands and Nigerian lowlands. Beare et al. (1994) also reported higher macroaggregates under zero-tillage than conventional tillage on a sandy clay loam from Georgia, USA.

3.3. Effects of tillage and cropping pattern on soil fractal features

Fractal dimensions computed using equation (6) and as influenced by tillage and cropping pattern are shown in Table 4. The average value for Dm from particle size distribution (PSD) is 2.998 with coefficients of determination (r2) between 0.52 and 0.65 ($P \leq 0.05$); whereas, fragmentation fractal dimensions (Df) from aggregate sizes ranged from 2.834 to 2.959 with higher r2 between 0.61 and 0.79 (Table 4). The constant value obtained for Dm was because this experiment was located on soil with similar texture. Observations from this study showed that only fragmentation fractal dimensions were significantly ($P \leq 0.05$) affected by tillage, where lowest Df values were obtained in no-tillage plots. Lower Df with no-tillage which corresponds to higher aggregate stability with this operation was also reported in the work of Filgueira et al. (1999) from uncultivated soil of 20 years. This agrees with Millan and Orellana (2001) that fractal models reflect differences in soil management.

The difference between Dm and Df, which indicates the degree of fragmentation according to Filgueira et al. (1999), showed higher values with no-tillage and significantly ($P \leq 0.05$) highest value (0.164) obtained in maize-cowpea intercropped plots, while lower values were observed under conventional tillage. Lower difference between Dm and Df with conventional tillage (Table 4) represents higher degree of fragmentation indicating aggregates breakdown into primary particles with this operation. This confirmed the observations of Xu et al. (2013) and Su et al. (2004) that fractal dimensions of soil aggregates are more sensitive to tillage operation, and this was reported by Martinez-Mena et al. (1999) as an indicator of soil erodibility. Therefore, fractal features or characteristics could be used to quantify possible soil degradation induced by soil management practices. Results obtained from difference between Dm and Df revealed maize-cowpea intercrop (0.164) followed by sole cowpea (0.149) presented in Table 4 were able to ameliorate degradation of the soil structure induced by conventional tillage operation over other cropping pattern.

Table 3: Aggregate size distribution (%) and aggregate stability indices

Tillage	Cropping Type	Aggregate sizes (mm)							
		5.66-2.00	2.00-1.00	1.00-0.50	0.50-0.25	<0.25	AR	MWD	ASC
NT	Control	31.27	8.49	9.94	9.11	41.20	1.497^{a*}	1.382^{a}	3.11^{ab}
	Cowpea	29.27	8.96	8.97	9.13	43.60	1.393^{ab}	1.315^{ab}	2.99^{abc}
	Maize	29.39	10.37	9.73	9.88	40.64	1.558^{a}	1.345^{a}	2.90^{abcd}
	Intercrop	34.98	8.83	8.04	6.54	41.62	1.511^{a}	1.494^{a}	4.07^{a}
CT	Control	8.06	10.98	13.43	11.34	56.19	0.787^{b}	0.660^{b}	1.46^{cd}
	Cowpea	10.37	11.54	13.20	10.34	54.49	0.840^{b}	0.742^{b}	1.49^{cd}
	Maize	13.60	11.89	14.19	11.53	48.80	1.081^{ab}	0.865^{ab}	1.36^{d}
	Intercrop	12.32	11.12	11.44	10.22	54.89	0.824^{b}	0.791^{b}	1.58^{bcd}
LSD(0.05):Tillage = 1.85; Cropping Type = 2.62; Aggregate sizes = 2.93; Tillage x Cropping Type x Aggregate size = 8.28									

NT- No-tillage, CT- conventional tillage, AR- aggregate ratio. MWD- Mean-weight diameter, ASC, aggregated silt+clay. *Values in columns with different letters were significantly different at $p < 0.05$.

3.4. Soil organic carbon

Total organic carbon (TOC) and organic carbon (OC) fractions were significantly impacted by the tillage practices and cropping pattern (Table 5). There was reduction in TOC concentrations following conventional tillage (CT) when compared with values obtained in no-tillage plots; whereas, OC fractions were increased with CT operation. As observed in the control plots, CT led to 28% reduction in TOC (18.2 g/kg) when compared with no-tillage (25.1 g/kg). This trend was similar with 20%, 15% and 3% reduction in TOC following CT in plots planted with sole cowpea, sole maize and maize-cowpea intercrop respectively. Free particulate organic carbon (fPOC) concentrations were slightly increased by CT except in maize-cowpea intercrop plots where the fPOC was 3.36 g/kg compared with 3.42 g/kg for no-tillage. Occluded organic carbon pools (oPOC), aHOC and nHOC were generally higher in NT plots, indicating that CT operation led to reduction in the concentrations of these stable OC fractions. The decrease in storage of TOC and other recalcitrant (stable) OC, i.e. oPOC, aHOC and nHOC, with consequent increase of the fPOC where CT was applied confirmed reduction in these indicators of soil quality by conventional tillage operation. This could be as noted by Zhao et al. (2017) and An et al. (2013) that tillage practice often increase the air exchange and oxygen availability thereby resulting in enhanced decomposition of organic matter and more release of the labile OC. Also, Adesodun et al. (2007) reported significant ($P < 0.05$) decreased in organic carbon in cultivated rainforest ecological area than the uncultivated area. Increment in the concentrations of TOC and fPOC observed in this study following CT, and for acid-hydrolyzable organic carbon (aHOC) by NT practice followed maize-cowpea intercrop > sole maize > sole cowpea with cropping pattern. This agrees with Rutigliano et al. (2004) that conversion of cropland to abandoned cropland with no tillage practice resulted in the enrichment of soil organic carbon.

3.5. Relationship between fractal features and other soil parameters

Correlation analysis was used to establish the relationship between the fractal dimensions (Dm and Df) particle size distribution, soil aggregate stability indices and soil organic carbon (Table 6). Correlation matrices showed that fractal dimension of PSD (Dm) had high significant positive correlation with sand ($r = 0.627$, $P < 0.05$, $n = 8$), a negative significant correlation with silt ($r = -0.675$, $n = 8$), high positive correlation with oPOC ($r = 0.574$, $n = 8$), weak positive correlation with TOC ($r = 0.30$) and nega-

Table 4: Fractal characteristics relative to the treatments

Tillage	Cropping system	D_m	D_f	Differenc (D_m - D_f)
NT	Control	2.998[a] (0.61)	2.865[b] (0.62)	0.133[a]
	Cowpea	2.998[a] (0.54)	2.849[b] (0.67)	0.149[a]
	Maize	2.998[a] (0.59	2.871[b] (0.68)	0.127[a]
	Maize-Cowpea intercrop	2.998[a] (0.65)	2.834[b] (0.72)	0.164[a]
CT	Control	2.997[a] (0.42)	2.959[a] (0.79)	0.038b
	Cowpea	2.998[a] (0.58)	2.953[a] (0.79)	0.045b
	Maize	2.988[a] (0.55	2.946[a] (0.76	0.052b
	Maize-Cowpea intercrop	2.988[a] (0.56)	2.946[a] (0.77)	0.052[b]

NT- No-tillage; CT- conventional tillage; Numbers in parentheses are coefficient of determination (n = 12). Values in columns with different letters were significantly different at $p < 0.05$

tive correlations r = -0.444 and -0.486 with fPOC and nHOC respectively. The relationship between fragmentation fractal dimension (Df) from soil aggregates show high significant positive correlation with micro-aggregate index ASC (r = 0.670, n = 8, P < 0.05) and clay content (r = 0.690, n = 8, P < 0.05); positive correlations with MWD (r = 0.50), TOC (r = 0.48) and fPOC (r = 0.515; and negative correlation with aHOC and nHOC, r = -0.417 and r = -0.32 respectively. The positive correlation between Dm and sand, and negative correlation with silt could be due to the local climate and its relation to soil weathering which did not agree with previous studies for example, Xu et al. (2013) who reported negative correlation with sand, and positive correlation with soil of higher silt and silt contents. The positive high correlation between aggregate fractal dimension (Df) and ASC, i.e. aggregate stability at micro-aggregate scale, than MWD indicated that this model (Df) was better at small size distribution scale. However, the overall trend supported Saiedi et al. (2017) who noted that fractal dimension can be used to explain aggregate stability.

The correlation analysis also showed very high significant relationship between MWD and AR (r = 0.977, n = 8, P < 0.0001), MWD and ASC (r = 0.960, n = 8, P < 0.0001); and MWD and ASC (r = 0.891, n = 8, P < 0.001). There were positive correlations between TOC and AR (r = 0.527), MWD (r = 0.50) and ASC (r = 0.556). For soil organic fractions, fPOC had weak negative correlation with the aggregate stability indices, while the relationship of other OC fractions (oPOC, aHOC, nHOC) was positive but low (Table 6). The negative correlation of free particulate organic carbon (fPOC) and aggregate stability showed disaggregation of this sandy loam soil with elevated fPOC contents. This supported results in Table 5 which show conventional tillage (CT) practice aided increase in fPOC than other OC fractions with corresponding decrease in soil stability (Table 3). Tisdall and Oades (1982) stated that there is content of OC above which there is no further increase in water-stable aggregation due to the increase in the negative charge on colloid surfaces favouring dispersion. Also, the relationship between the different SOC and aggregate stability indices as presented in Table 6 showed total OC rather than OC fractions to be more important in maintaining the structural stability of this soil. This agrees with Adesodun et al. (2001, 2004) who reported that car-

Table 5: Soil organic carbon fractions relative to the treatments

Tillage	Cropping system	TOC (g kg^{-1})	fPOC (g kg^{-1})	oPOC (g kg^{-1})	aHOC (g kg^{-1})	nHOC (g kg^{-1})
NT	Control	23.1[ab]	28.2[abc]	10.1[b]	15.3[b]	14.0[d]
	Cowpea	24.5[ab]	26.0[bc]	12.7[a]	19.9[b]	22.1[b]
	Maize	28.7[a]	25.2[c]	11.3[a]	24.1[ab]	25.2[a]
	Maize-cowpea intercrop	29.2[a]	34.2[a]	10.3[b]	29.1[a]	14.9[cd]
CT	Control	18.2[b]	31.3[abc]	8.4[c]	17.4[b]	16.8[c]
	Cowpea	19.6[b]	28.8[abc]	11.7[a]	17.[7b]	16.1[cd]
	Maize	24.3[ab]	31.9[ab]	11.7[a]	15.5[b]	14.7[cd]
	Maize-cowpea intercrop	28.2[ab]	33.6[a]	8.3[c]	6.5[c]	23.9[ab]

NT- No-tillage; CT- conventional tillage; Numbers in parentheses are coefficient of determination (n = 12). Values in columns with different letters were significantly different at $p < 0.05$

Table 6. Correlation matrices of fractal dimensions and some soil properties

	D_m	D_f	Sand	Silt	Clay	AR	MWD	ASC	TOC	fPOC	oPOC	aHOC	nHOC
D_m	1.000												
D_f	0.143	1.000											
Sand	0.627*	-0.287	1.000										
Silt	-0.675*	-0.172	-0.788*	1.000									
Clay	-0.138	0.690*	-0.596	-0.026	1.000								
AR	0.432	0.387	0.332	-0.587	0.226	1.000							
MWD	0.432	0.500	0.168	-0.510	0.391	0.977***	1.000						
ASC	0.312	0.670*	0.065	-0.474	0.512	0.891**	0.960***	1.000					
TOC	0.300	0.480	0.428	-0.369	-0.213	0.527	0.500	0.556	1.000				
fPOC	-0.444	0.515	-0.534	0.378	0.373	-0.427	-0.326	-0.170	0.048	1.000			
oPOC	0.574	-0.067	0.083	-0.160	0.073	0.438	0.365	0.222	-0.235	0.599 *	1.000		
aHOC	-0.292	-0.417	0.292	-0.303	-0.080	0.318	0.308	0.191	-0.049	-0.434	-0.203	1.000	
nHOC	-0.486	-0.318	-0.143	0.406	-0.298	0.058	0.051	-0.013	0.061	-0.381	0.001	0.330	1.000

* $P < 0.05$; ** $P < 0.01$, *** $P < 0.001$, Dm- mass fractal dimension of PSD, Df- fragmentation dimension of aggregates, AR= Aggregate ratio, MWD- mean-weight diameter, ASC- aggregated silt+clay, TOC- total organic carbon, fPOC- free particulate organic carbon, oPOC- occluded particulate organic carbon, aHOC- acid-hydrolizable organic carbon. nHOC- non-acid hydrolyzable organic carbon.

bohydrate and other labile organic matter fractions did not contribute much to the aggregation and stabilization of soil particles particularly when dealing with fragile tropical soils which are exposed to high risk of water erosion.

4.0. Conclusion

Results from this study showed that sand followed by clay were the predominant particles for this soil. Also, significant decreased in the proportion of larger soil aggregate fractions (> 2.00 mm) and corresponding increase in smaller aggregate fractions (< 2.00 mm) were obtained following conventional tillage practice compared with no-tillage. Effects of the different tillage and cropping pattern revealed better stability of the soil structure under no-tillage. Also, maize-cowpea intercrop followed by sole cowpea was better in reversing the declined in aggregate stability due to conventional tillage. Fractal dimensions of the particle size were not affected by the treatments; however, fragmentation fractal dimension (D_f) from aggregates sizes was affected by tillage where higher D_f values were recorded with conventional tillage, and lower values corresponding to higher soil stability were recorded under no-tillage practice. This study showed fragmentation fractal dimension of soil aggregates rather than fractal dimension of particle sizes reflect impacts of the management options better for this soil; and maize-cowpea intercrop was able to ameliorate soil degradation due to conventional tillage reported as fragmentation of aggregates.

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