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Distribution of carbohydrate pools within water-stable aggregates of an Ultisol in Southern Nigeria

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A b s t r a c t. This study was undertaken to evaluate the effects of different organic and inorganic amendments on carbohydrate distributions in water-stable aggregates of a degraded tropical Ultisol at Nsukka in southern Nigeria. All the amendments improved the aggregate stability (AS) over the control at all the sampling periods. In each aggregate size fraction, carbohydrate concentrations at all the sampling periods varied in the order of R-CHOt > R-CHOh > R-CHOc, irrespective of the type of amendment. The distribution of the carbohydrate fractions within the water-stable aggregates generally decreased with increasing time of sampling. At the 3rd and 6th months of sampling all the carbohydrate fractions decreased with decreasing aggregate diameter up to 0.5-0.25 mm, beyond which there was an increase in those fractions in the microaggregates (< 0.25 mm). At the 12th month, the decrease ranged from 49 to 55% for all the treatments. The RW+F, PM and RW+PM treatments had the highest concentration of carbohydrates up to the 6th month, after which there was a decline. Generally, the correlations between the carbohydrate fractions and WSA were low at all the sampling periods. This signifies that these labile organic matter pools are not contributing much to the aggregation and stabilization of soil particles.

K e y w o r d s: carbohydrate concentrations, water-stable aggregates, Nigerian Ultisol

INTRODUCTION

The binding of soil particles into stable aggregates is essential for the formation of optimum soil tilth (Harris *et al.*, 1966). Diverse organic and inorganic soil constituents are involved in binding soil particles into water-stable aggregates (Dormaar, 1983). An improvement in soil aggregation usually follows the addition of organic amendments to the soil. However, considerable controversy exists as to the actual role of organic matter (OM) in soil aggregation and aggregate stability. Some research workers (Chaney and Swift, 1984; Christensen, 1986) found a direct correlation between soil organic matter (SOM) content and aggregate stability, whereas others (Dormaar, 1983; Hamblin and Greenland, 1977) reported that the fractions of OM rather than the total amount *per se* are important in modifying the structural stability of aggregates.

There are also differences in the interpretation of the actual OM constituents that are responsible for improving soil aggregation. Dormaar (1983) showed that the polyuronides and phenols are associated with the macroaggregates (> 0.25 mm diameter), whereas Tisdall and Oades (1982) reported that polysaccharides only act as transient binding agents which are rapidly decomposed by microorganisms and are predominantly associated with the > 0.25 mm transient, stable aggregates. Others (Adesodun *et al.*, 2001; Insam, 1996; Piccolo, 1996; Piccolo and Mbagwu, 1999; Spaccini *et al.*, 2001), however, have recently shown that carbohydrates cannot be involved in long-term stabilization of soil aggregates because they are also decomposed by microorganisms in soils.

It has been suggested that humic materials associated with amorphous Fe, Al and aluminosilicates are the persistent binding agents of microaggregates (< 0.25 mm diameter) (Chaney and Swift, 1986; Edwards and Bremner, 1967; Piccolo and Mbagwu, 1989; 1990; Tisdall and Oades, 1982). Following the acceptance of the paradigm that polysaccharides are involved in transient stabilization of soil aggregates, a number of studies have been published in the attempt to confirm the relation between the content of

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carbohydrates in soils and the aggregate stability (Chesire, 1979; Tisdall and Oades, 1982). However, most of these studies were on soils of the temperate region, with relatively slow rates of OM turnover. Not much study exists in the literature on the role of the labile OM pools in aggregate stability of tropical soils. The objective of this study is to assess the role of the carbohydrate fraction of OM in aggregate stability of an Ultisol in Nigeria by regressing its distribution in water-stable aggregates with the mean-weight diameter (MWD) of stable aggregates over a 12 month period.

MATERIALS AND METHODS

Study area

This research was carried out in the Farm of University of Nigeria, Nsukka (06° 52'N, 07° 24'E). The area is characterized by a tropical climate with marked wet and dry seasons and a mean annual rainfall of about 1700 mm. The soil is deep, well drained and red to brownish-red in colour, and derived from sandy deposits of False-bedded sandstone (Orajaka, 1975). This is a sandy clay loam soil (Nwadialo, 1989) and is classified as *Typic Kandiustult* (Nwadialo, 1989; Soil Survey Staff, 1986) or *Dystric Nitosol* (FAO/UNESCO, 1988). It has low pH (5.02), exchangeable bases and exchangeable sodium percentage (ESP), but moderate CEC.

Experiment layout

Field study

A land area of 0.0876 ha was used for this study. The experiment layout was the Randomized Complete Block Design (RCBD) with six treatments, each replicated four times. The treatments were applied as follows: i) control – no amendment (C); ii) complete fertilizer alone, NPK (12-12-17) applied at the rate of 480 kg ha^{-1} (F); iii) rice-mill waste alone (i.e., rice bran + rice-husk) applied at the rate of 10 t ha^{-1} (RW); iv) rice-mill waste (RW) + complete fertilizer (F) applied at the rate of 10 t ha^{-1} RW + 480 kg ha^{-1} F (RW + F); v) poultry manure alone applied at the rate of 10 t ha^{-1} (PM); and rice-mill waste + poultry manure applied at the rates of 5 t RW + 5 t PM ha^{-1} (RW + PM). All the amendments were applied in a single dose.

At the 3rd, 6th and 12th months after application of the amendments (i.e., in October 1995, January 1996, and July 1996) bulk soil samples were collected from the 0-20 cm depth, air-dried and sieved to obtain the < 4.75 mm natural aggregates.

Determination of aggreagate stability

The distribution of water-stable aggreates was estimated by the wet-sieving technique, described in detail by Kemper and Rosenau (1986). In the procedure, 40 g of the < 4.75 mm aggregates were placed on the topmost of a nest of sieves of diameters 2, 1, 0.50 and 0.25 mm and pre-soaked in distilled water for 10 min before oscillating in water 20 times at the rate of 1 oscillation/s using an amplitude of 4 cm. After sieving the aggregates from each sieve were dried at 105°C for 24 h and weighted. The mass of the < 0.25 mm aggregates was obtained by difference. The percent of the true water-stable aggregates (WSA) in each of the following size ranges, 4.75-2, 2-1, 1-0.5, 0.5-0.25 and < 0.25 mm, were determined after correction for the sand fraction in each size using the method of van Bavel (1950) as modifed by Kemper and Rosenau (1986) expressed as:

$$\mathrm{MWD} = \sum_{i=1}^{n} \mathrm{XiWi}$$

where: MWD – the mean-weight diameter of water stable aggregates, Xi – mean diameter of each size fraction (mm), Wi – the proportion of the total sample weight (WSA) in the corresponding size fraction. Higher MWD values imply higher aggregate stability.

Carbohydrate distribution

The carbohydrate distribution in each water-stable aggregate was determined in duplicate in three types of soil extracts, i.e., dilute acid, hot water and cold water. In the dilute acid-soluble extract 1 g of soil was mixed with 10 ml of 0.25 M H_2SO_4 and shaken in a rotary shaker for 16 h; in the hot water-soluble extract 1 g of soil was mixed with 10 ml of hot distilled water (85°C) and heated for 2 h 30 min; and in the cold water extract 1 g of soil was mixed with 10 ml of cold distilled water and shaken in a rotary shaker for 16 h.

After each extraction and centrifugation, 2 ml of the supernatant solution were used to determine the carbohydrate concentration using the phenol-sulphuric acid method (Dubios *et al*., 1956). The absorbance was read in a spectrophotometer (Jouan Model VP 10.12) at 490 nm using glucose standards.

Data analysis

Simple correlation analysis of the carbohydrate pools with the water-stable aggregates (WSA) was performed according to the existing procedure (Little and Hills, 1972) in order to evaluate the influence of those OM fractions on aggregate stability.

RESULTS AND DISCUSSION

Aggregate size distribution and stability and organic matter content

At each sampling, the 1-0.5 mm diameter WSA made up the highest percentage of the whole soil in all the treatments, containing an average of 54, 35 and 34% at the 3rd, 6th and 12th months following the application of amendments, respectively. With time the treatments generally reduced the proportions of the 2-0.5 mm aggregates while increasing those of the larger 2-4.75 mm size ranges. This implies that these amendments were binding the smaller aggregates into larger ones, an observation which supports the hierachical model of aggregation (Piccolo and Mbagwu, 1989) for soils where OM is a major binding agent. The stability of intact WSA, as measured by the mean-weight diameter (MWD), increased with time of sampling, with average values of 0.826 mm at the 3rd month, 1.197 at the 6th month, and 1.299 mm at the 12th month (Table 1). At each sampling time, the amendments significantly ($P < 0.05$) increased the aggregate stability over the control. However, OM decreased with time over the entire sampling period. The highest concentration of OM (19.1 g kg^{-1}) was obtained from RW treatment at the 3rd month of sampling. Also at the 6th month of sampling, the highest concentration in OM occurred in RW whereas at the 12th month this was obtained with the F treatment. Throughout all sampling times the lowest OM value occurred in the control treatment. This diminishing OM concentration with time confirms our earlier results (Mbagwu, 1992a) and points to the decay of organic materials with time.

Carbohydrate distribution in water-stable aggregates

The carbohydrate pools considered are acid-hydrolyzable fraction (R-CHOt, i.e., the dilute acid-soluble carbohydrates), the hot water-soluble carbohydrates (R-CHOh, i.e., polysaccharides which are part of the dilute acid-soluble carbohydrates) and the cold water-soluble carbohydrates (R-CHOc i.e., the free, uncombined sugars and the disaccharides).

The general trend showed that R-CHOt concentration in the WSA decreased with decreasing size of the macroaggregates (4.75-0.25 mm) but increased in the microaggregates (< 0.25 mm) irrespective of the treatment applied. There was also a progressive decrease in R-CHOt with time (Table 2) even as aggregate stability increased (Table 1). The concentrations of R-CHOt with time, pooled over all the amendments, varied at the 3rd month from 500 to 759 mg kg^{-1} in the macroaggregates and from 660 to 908 mg kg^{-1} in the microaggregates (Table 2). At the 6th month, the range was from 290 to 666 mg kg^{-1} in the macroaggregates and from 386 to 731 mg kg^{-1} in the microaggregates. At the 12th month the range varied from 262 to 385 mg kg^{-1} in the macroaggregates and from 357 to 431 mg kg^{-1} in the

T a b l e 1. Distribution of water-stable aggregates and organic matter (g kg^{-1}) with time

Amendments	Aggregate sizes (mm)					MWD (mm)	OM (g kg^{-1})
	4.75-2	2-1	1-0.5	0.5-0.25	< 0.25		
		3rd month					
C	3.9	5.9	59.6	19.7	10.7	0.759	11.6
F	6.1	11.6	52.7	18.4	11.3	0.862	17.2
RW	5.9	8.4	45.7	25.7	14.4	0.787	19.1
RW+F	3.8	7.6	55.7	24.4	8.6	0.762	18.4
PM	7.9	11.1	56.3	16.9	7.9	0.931	16.6
RW+PM	5.8	10.2	55.4	20.7	8.0	0.854	17.9
LSD (0.05)	0.63	0.90	1.93	1.40	1.03	0.030	0.381
		6th month					
C	15.3	10.9	42.3	23.1	8.6	1.095	11.2
F	14.4	16.0	38.1	26.3	5.3	1.115	14.8
RW	21.1	10.2	33.2	29.4	6.1	1.229	16.7
RW+F	21.1	12.4	35.3	24.0	7.1	1.261	15.5
PM	18.9	18.1	28.1	24.1	10.8	1.227	14.7
RW+PM	20.0	14.9	35.0	23.0	7.1	1.257	16.4
LSD (0.05)	1.20	1.26	1.94	1.01	0.80	0.030	0.128
		12th month					
C	22.3	9.3	38.4	20.9	8.6	1.271	10.7
F	25.9	10.8	31.3	21.1	10.9	1.367	15.0
RW	28.6	10.6	32.9	19.3	8.5	1.456	12.6
RW+F	21.2	11.2	35.5	25.8	6.4	1.253	14.8
PM	24.3	12.5	30.5	22.0	10.8	1.336	13.3
RW+PM	16.4	11.3	37.8	24.4	10.1	1.113	14.3
LSD (0.05)	1.72	0.43	1.36	0.99	0.71	1.050	0.092

T a b l e 2. Distribution of acid-soluble carbohydrate pools within water-stable aggregates of organic-waste amended Ultisol in Nigeria

Amendments	Aggregate sizes (mm)				
	4.75-2	2-1	1-0.5	0.5-0.25	< 0.25
			3rd month		
C	459	453	490	453	468
F	645	701	619	517	735
RW	742	697	579	546	680
RW+F	690	565	553	515	735
PM	724	619	576	500	706
RW+PM	683	650	596	544	660
LSD (0.05)	142	108	99	82	176
			6th month		
C	251	267	290	287	330
F	495	337	349	343	422
RW	339	332	356	294	386
RW+F	646	480	500	487	624
PM	562	567	586	535	692
RW+PM	666	631	546	505	731
LSD (0.05)	221	216	169	183	216
			12th month		
C	234	222	231	262	322
F	352	332	297	275	423
RW	360	325	305	291	390
RW+F	346	314	279	274	357
PM	385	290	306	279	362
RW+PM	347	307	346	306	431
LSD (0.05)	116	93	102	29	84

microaggreagates (Table 2). The distributions of R-CHOh (Table 3) and R-CHOc (Table 4) followed similar patterns even though their absolute amounts were lower than in the case of the R-CHOt.

The highest concentrations of carbohydrates in the aggregate classes, across all the treatments, occurred at the 3rd month (Table 2). Six months after the application of the amendments, there was a decline in the R-CHOt of the C, F and RW-treated plots, while the RW + F, PM and RW + PM plots maintained a high R-CHOt concentration. At the 12th month, there was a decline in the R-CHOt concentration across all the treatments. This differential performance of the amendments across the sampling periods may be related to the fact that RW is highly fibrous, with a high C:N ratio (44.0), which decreased the rate of mineralization of the constituent OM. However, the addition of a fertilizer and PM to the RW increased the rate of mineralization of RW by decreasing the C:N ratio.

This observation is similar to that reported by Mbagwu (1992a, 1992b) that plots amended with those organic wastes had about 90% higher mineralization rates than unamended plots. Hence the incorporation of RW + F, PM and RW + PM temporarily maintained high levels of carbohydrates relative to the control (Table 2). This increase diminished with time, reaching a stabilized level across all the treatments at the 12th month.

Generally, in terms of carbohydrate content, the results indicate that carbohydrate influence on soil aggregation was stronger on the macro- (4.75-0.25 mm) than the micro- (< 0.25 mm) aggregates. This confirms the findings of Tisdall and Oades (1982) that polysaccharides are essential in aggregate stabilization of the predominantly > 0.25 mm, transiently stable aggregates from the temperate region.

Carbohydrate pools and aggregate stability

The relationship between the carbohydrate pools and WSA (Table 5) showed significant correlations between the R-CHOh and R-CHOc and some water-stable aggregates with ‘r’ varying from –0.53* to 0.90** at the 3rd month, and between all the carbohydrate pools and some aggregate sizes with ‘r’ varying from –0.53* to 0.81 at the 6th month and from 0.59* to 0.76** at the 12th month following the application of the amendments. Generally, significant improvements in the size of water-stable aggregates associated with the carbohydrate pools were less apparent in all the other classes (Table 5).

This result, compared with Table 1, shows on the average that a MWD increase of 31% at the 6th month relative to the 3rd month was accompanied by a 26% decrease in R-CHOt, and a MWD increase of 36% at the 12th month relative to the 3rd month was accompanied by a

T a b l e 3. Distribution of hot water-soluble carbohydrate pools within water-stable aggregates of organic-waste amended Ultisol in Nigeria

Amendments	Aggregate sizes (mm)				
	4.75-2	2-1	1-0.5	0.5-0.25	< 0.25
			3rd month		
C	167	170	188	156	216
F	286	229	196	184	277
RW	291	277	235	195	243
RW+F	267	221	214	176	231
PM	210	183	193	163	231
RW+PM	237	209	185	168	237
LSD (0.05)	109	86	22	18	32
			6th month		
C	132	169	155	137	178
F	215	197	170	162	227
RW	200	174	158	141	182
RW+F	214	185	159	142	184
PM	261	188	183	154	254
RW+PM	222	189	176	154	224
LSD (0.05)	103	17	16	14	37
			12th month		
C	121	135	132	120	187
F	240	214	191	172	262
RW	226	195	200	149	218
RW+F	205	188	136	138	218
PM	178	161	147	126	198
RW+PM	182	151	146	143	197
LSD (0.05)	89	43	38	36	46

T a b l e 4. Distribution of cold water-soluble carbohydrate pools within water-stable aggregates of organic-waste amended Ultisol in Nigeria

Amendments	Aggregate sizes (mm)				
	4.75-2	2-1	1-0.5	0.5-0.25	< 0.25
			3rd month		
C	43	25	21	23	41
F	69	48	38	25	54
RW	76	54	46	33	44
RW+F	61	46	46	32	48
PM	51	33	32	25	46
RW+PM	55	44	37	26	56
LSD (0.05)	21	18	17	9	11
			6th month		
C	39	23	20	21	39
F	60	54	47	41	58
RW	40	40	39	27	51
RW+F	42	29	29	27	42
PM	52	48	36	32	65
RW+PM	49	56	45	45	81
LSD (0.05)	15	27	17	19	32
			12th month		
C	31	22	20	21	34
F	51	41	40	21	44
RW	38	38	33	20	49
RW+F	40	26	29	19	41
PM	50	38	34	24	57
RW+PM	46	37	43	31	73
LSD (0.05)	16	11	14	8	21

T a b l e 5. Relationship between carbohydrate pools and percentage water-stable aggregates (WSA) (N = 18)

Carbohydrate pools	Water-stable aggregates (WSA), mm	Correlation coefficient (r) at the		
		3rd month	6th month	12th month
Acid-hydrolyzable carbohydrates	4.75-2.00	-0.14	0.35	0.39
	2.00-1.00	0.35	0.55*	-0.76**
	1.00-0.50	-0.01	0.76**	0.59*
	0.50-0.25	0.002	-0.53*	0.18
	< 0.25	0.11	0.50*	0.56*
Hot water-soluble carbohydrates	4.75-2.00	-0.62**	-0.21	0.42
	2.00-1.00	-0.21	0.81**	-0.69**
	1.00-0.50	-0.74**	-0.65**	-0.33
	0.50-0.25	0.65**	-0.003	-0.45
	< 0.25	0.36	0.39	0.03
Cold water-soluble carbohydrates	4.75-2.00	-0.53*	0.45	0.67**
	2.00-1.00	-0.34	0.71**	0.34
	1.00-0.50	-0.33	-0.12	0.001
	0.50-0.25	0.90**	-0.09	0.24
	< 0.25	-0.33	0.06	0.08

With the exception of the figures with asterisks, the rest are not significant at $P < 0.05$. *Significant at $P = 0.05$, **Significant at $P = 0.01$.

49% decrease in R-CHOt. This suggests that the amendments applied improved aggregate stability with time while the contribution of the carbohydrate pools decreased with time, indicating that only a part of the change in aggregate stability was related to the carbohydrates. These results also confirm the findings of others (Adesodun *et al*., 2001; Baldock *et al*., 1987; Insam, 1996; Piccolo, 1996; Piccolo and Mbagwu, 1999; Spaccini *et al*., 2001) that the correlation between either the carbohydrate content or the content of individual monosaccharides and the stability of aggregates in soils is generally either non- or only slightly significant.

CONCLUSIONS

1. Carbohydrates have a residence time hardly exceeding a few months in these tropical sandy soils.

2. Carbohydrates provide a short-term improvement in aggregate stability of soils, especially in the transiently stable macroaggregates.

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