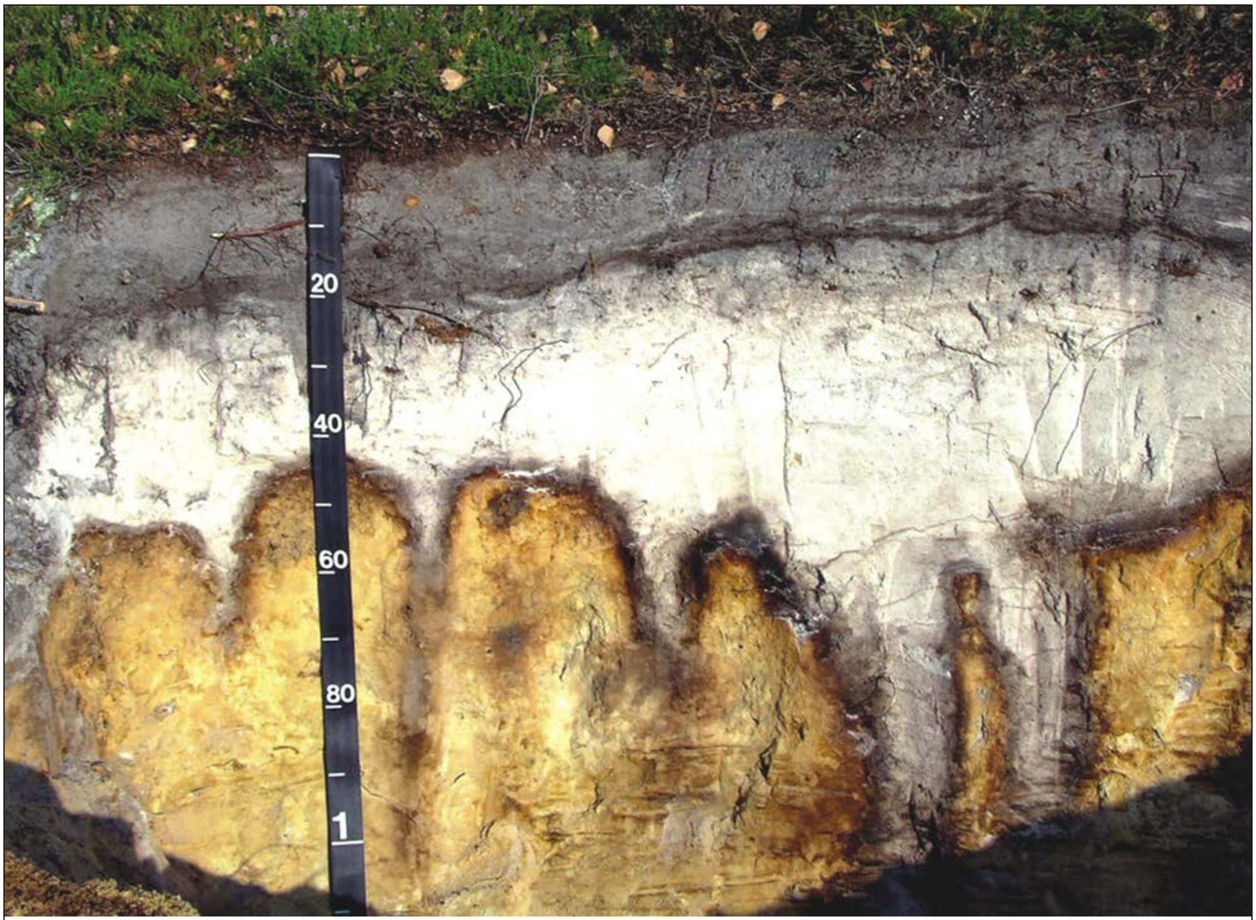

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Soil Organic Matter and Carbohydrate Contents of a Dystric Leptosol Under Organic Waste Management and Their Role in Structural Stability of Soil Aggregates

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Abstract: The structural stability of soils has an impact on a wide range of processes that influence crop growth. This study evaluated the role of soil organic matter (SOM) and carbohydrate pools of soil organic matter (cold water, hot water and dilute acid soluble) on the structural stability of organic waste amended dystric leptosol in Abakaliki area southeastern Nigeria. The wastes used for soil amendment were Poultry Droppings (PD), Cow Dung (CD), Sewage Sludge (SS) and Swine Waste (SW) applied at 0, 10 and 20 Mg ha^{-1} concurrently for two years. The results of the study showed that SOM was significantly higher in waste amended plots than in the control by 122-179 and 166-226% in the first and second cropping seasons, respectively. Observed mean increase in soil carbohydrate content was 169 mg kg^{-1} (cold water soluble), 476 mg kg^{-1} (hot water soluble) and 593 mg kg^{-1} (dilute acid soluble) in the first cropping season. In the second cropping season 193% (cold water soluble), 86% (hot water soluble) and 93% (dilute acid soluble) increase were observed relative to the control in the second cropping season. Aggregate stability correlated positively (r = 0.68*) with SOM and poorly with soil carbohydrate (cold water, hot water and dilute acid soluble) content. The results from this study showed that SOM contributes to soil aggregate stability whereas the soil carbohydrate pool was not effective in aggregation of the soil studied.

Key words: Carbohydrate, soil organic matter, aggregate stability, organic wastes

INTRODUCTION

Maintaining an adequate amount of organic matter in the soil stabilizes soil structure and makes it more resistant to degradation. Hamza and Anderson (2005) identified the most common means by which organic matter influences soil structure and compactibility as: (a) binding soil mineral particles, (b) reduction of aggregate wettability and (c) influencing the mechanical strength of soil aggregates, which is the measure of coherence of inter-particle bonds.

Numerous research works have been devoted to the chemical and physicochemical characterization of Soil Organic Matter (SOM) (Spaccini *et al*., 2004; Bongiovanni and Lobartini, 2006) and the establishment of relationships between the quality and quantity of SOM and water stable aggregates (Tisdall and Oades, 1982). Soil carbohydrates, which represent from 5 to 25% of

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SOM (Stevenson, 1994), constitute a significant part of the labile pool of SOM and are most affected by land use changes (Guggenberger *et al*., 1999). Kiem and Kögel-Knabner (2003) noted that the soil carbohydrate pool is composed of polysaccharides derived from various sources, i.e., plant and animal tissues, plant mucilage, cellular tissues and extracellular products of soil microbes. The presence of carbohydrates in soils has manifold effects on biological, physical and chemical soil properties. They represent the major carbon and energy source for soil organisms, thus governing biological activity (Haider, 1992). Polysaccharides, mainly those of microbial origin, act as binding agents between soil particles, thus influencing soil structure/aggregation. Large emphasis had been given to the action of polymeric carbohydrates in stabilising soil structure (Tisdall and Oades, 1982; Tisdall and Waters, 1991). However, due to the temporary biological stability of carbohydrates (Insam, 1996), their long-lasting role in improving soil physical properties may not be assumed in all soil conditions (Piccolo, 1996; Piccolo and Mbagwu, 1999). However, considerable controversy exists from studies carried out in temperate regions on the actual role of organic matter in soil aggregate stability. Some researchers (Dormaar, 1983) reported that it is some fractions of SOM rather than the amount per se that modify the structural stability of aggregates whereas others (Chaney and Swift, 1984; Christiensen, 1986) found a direct correlation between total SOM level and aggregate stability. In contrast, some workers have not found such positive correlation (Dexter *et al*., 1984) and others have reported different behaviour for different types of organic matter (Ekwue, 1990). Still others have reported different behaviour for the same type of organic matter at different soil conditions (Soane, 1990). These differences seem to be related to the type of organic matter, C/N ratio and the degree of resistance to decomposition as well as to soil type and environmental conditions such as moisture and temperature. The type of organic matter is also important (Hamza and Anderson, 2005).

In the tropics, differences in opinion on the actual fraction of SOM that are responsible for improving soil aggregation also exist. For instance, while Adesodun and Mbagwu (2001) reported that R-CHO pool of the soil was not effective in the stability of soil aggregate, Mbagwu and Piccolo (1998) and Durtate *et al*. (1993) showed that R-CHO participate in aggregate stability when they are in conjunction with more humified SOM pools. Recently, researches on carbohydrate content of SOM which according to Oades (1984) function as cementing agent has received considerable attention. Haynes (2005) observed that various extractable organic matter fractions have also been suggested to be important, including hot water-extractable and dilute acid-extractable carbohydrates, which are involved in stabilization of soil aggregates and permanganate-oxidizable C. According to Spaccini *et al*. (2004) the relationship between SOM and soil aggregation or structure formation was described by Tisdall and Oades (1982) in a conceptual model, affected by three types of aggregation agents. In soils, where the SOM is the main binding agent, aggregates of different sizes can be formed. Primary particles and clay microstructure are bound together with bacterial and fungal debris into extremely stable microaggregates which may be bound together with fungal and plant debris giving a larger microaggregates. The humic matter, considered as a persistent cementing agent, is involved in stabilizing microaggregates. These microaggregates are bound into macroaggregates, due to the effect of transient binding agents (polysaccharides derived from plants and microorganisms). Kaiser and Zech (1999) and Spaccini *et al*. (2004) showed that the intensity of cultivation, soil type and texture, original soil carbon status and quality, distribution of natural aggregates in soils and the ambient climate affects the quality and quantity of carbohydrates in soils.

In Nigeria, previous studies showed that soil carbohydrate content decreased with decreasing wet-aggregate size in the humid south, whereas with dry-aggregates the opposite was the case in the cool plateau of the north (Mbagwu and Piccolo, 1998; Adamu *et al*., 1997). Carbohydrates play a major role as structural (e.g., cellulose, hemicellulose and pectin) components of plants and provide a major source of energy for microbial processes in soils. Residues with higher contents of carbohydrates and amino acids and lower contents of phenolic acids have faster C mineralization rates than residues with lower carbohydrate contents and higher phenolic acid contents. If carbon sequestration in soils is to be managed, the quantitative composition of different plant residues, microbial biomass and the impact of different plant biochemistry on carbon mineralization and cycling must be known (Martens and Loeffelmann, 2002; Nacro *et al*., 2003). It is important to further understand the relationship between SOM, its soil carbohydrate fraction and the stability of soil aggregates under different soil management practices in the tropics. This will help in making available regional data for general SOM modeling.

The objectives of this study were to evaluate the organic matter and carbohydrate contents of dystric leptosol under waste management systems and to assess the actual role of organic matter and carbohydrate in soil aggregate stability of a tropical soil.

MATERIALS AND METHODS

Soil Characterization

This study was carried out at the Research and Teaching Farm of Ebonyi State University, Abakaliki. The area is located within Latitude 06°4'N and Longitude 08°65'E within the derived savannah zone of South Eastern Nigeria. It has a mean annual temperature of between 27-32°C with mean annual rainfall of approximately 1700 mm, received between April and November. The soil is formed from shale parent material. It is shallow with unconsolidated parent material within 1 m of the soil surface and classified as Dystric Leptosol (Anikwe *et al*., 1999).

Field Methods

The experiment was conducted during the 1999 and 2000 planting seasons. At the beginning of the experiment in March 1999, the predominant vegetation *Imperata cylindrica*, was cleared manually. The soil was prepared (tilled) using traditional hoe. A total land area of 42.5×14 m (0.0595 ha) was marked out for the experiment. The field was marked out into three blocks and each block further divided into twelve experimental units of 3×4 m (12 m^2). These were separated by 0.5 m alley while the blocks were 1 m apart.

A total of 36 experimental units were set out in the field using split plot in Randomized Complete Block Design (RCBD). Four types of animal wastes [(Cow Dung (CD), Poultry Droppings (PD), Swine Waste (SW) and Sewage Sludge (SS)] were applied at the rates of 0, 12 and 24 kg/plot on dry weight basis (equivalent to 0, 10 and 20 Mg ha^{-1}). The types of wastes were placed on the main plot whereas the rates were placed on subplots. The wastes CD, SW and PD were collected from Animal Science Farm of the University whereas SS was collected from sewage disposal site at the University of Nigeria, Nsukka. The wastes were air dried at room temperature (26°C), crushed to fine particles and analyzed for their organic matter content. Organic matter value is low (10.3 g kg^{-1}) in the soil and high in the organic wastes (108-298 g kg^{-1}) (Table 1).

The wastes were spread on the appropriate plots before the beds were prepared. Maize (*Zea mays* L. variety Oba super II) was planted 5 days after land preparation at two seeds $hole^{-1}$ at 5 cm depth using 0.75×0.25 m spacing. This was later thinned down to one plant $hole^{-1}$ 1 week after

Table 1: Organic matter and nutrient contents of the wastes and soil before the study

Parameters	Unit	Soil	PD	CD	SW	SS
Total N	(g kg^{-1})	0.59	21.4	18.0	21.0	20.0
OM	"	10.30	298.0	138.0	243.0	108.0
Ca	"	2.10	64.0	46.0	53.0	30.0
Mg	"	1.10	19.6	20.4	21.6	12.0
Na	"	0.17	7.2	3.6	4.4	2.6
K	"	0.13	32.0	4.5	6.3	4.3

PD = Poultry Droppings, SW = Swine Waste, SS = Sewage Sludge, CD = Cow Dung emergence to give a total of 53,000 plants ha^{-1}. The experimental area was kept relatively weed free using traditional hoe throughout the period of the experiment. The same procedure was carried out during the second planting season.

Laboratory Determinations

At the end of each planting season (120 DAP) soil samples were collected from each plot at a depth of 0-0.20 m. The soil samples were composited, air dried at room temperature (about 26°C), passed through a 2 mm sieve and used for analysis. The soil organic carbon was determined by Wakley/Black procedure (Nelson and Sommers, 1996). Exchangeable cations were determined by the method of Thomas (1982). Total nitrogen was determined using the method of Bremner (1996). Aggregate stability was estimated by the wet sieving technique described by Nimmo and Perkins (2002). The carbohydrate concentration was determined using the phenol-sulphuric acid method (Dubios *et al*., 1956). The carbohydrate fractions in the whole soil samples (<4.75 mm fraction) were determined in duplicate samples in three types of soil extract viz. dilute acid soluble, hot water-soluble and cold water soluble as follows:

- One gram of soil was mixed with 10 mL of 0.25 M H_2SO_4 and shaken in a plane rotary machine for 16 h (dilute acid soluble carbohydrate).
- One gram of soil was mixed with 10 mL of hot distilled water (85°C) and heated for 2.5 h (hot water extractible soluble carbohydrate).
- One gram of soil was mixed with 10 mL of cold distilled water (25°C) and shaken in a plane rotary shaker for 16 h (cold water extractible soluble carbohydrate).

All the three suspensions were centrifuged at 3,000 rpm for 30 min. After centrifugation, 2 mL of the supernatant solution were siphoned and used to determine the carbohydrate concentration using the phenol-sulphuric acid method. The absorbance was read in a spectrophotometer (Jouan Model Vp 10.12) at 490 nm. The calibration curve was obtained using glucose standard.

Data Analyses

Data collected from the study were analyzed using correlation and analysis of variance (ANOVA) tests based on the split plot in RCBD according to the procedures outlined by Steel and Torrie (1980).

RESULTS AND DISCUSSION

Effect of the Wastes on Soil Organic Matter Content

Application of the wastes increased the SOM content in both planting seasons (Table 2). Soil organic matter values of between 19.8-24.8 and 18.6-22.6 g kg^{-1} were obtained in the amended plots in the first and second cropping seasons, respectively. These values represent an increase ($p = 0.05$) of 122-179 and 166-226% relative to the control. Swine Waste (SW) application at 20 Mg ha^{-1} gave the highest value 24.8 g kg^{-1} corresponding to a significant increase of 179% relative to the control in the first planting season whereas SS at 20 Mg ha^{-1} gave the highest value of 22.8 g kg^{-1} representing 226% increase in the second cropping season.

At the rate of 10 Mg ha^{-1} in the first planting season, PD had the highest SOM content (21.7 g kg^{-1}). This was significantly higher than SOM content in CD, SS and SW amended plots by 4.6, 7.8 and 8.8%. However, in the second planting season, SS amended plots had SOM content of 21.4 g kg^{-1} and this was significantly higher than SOM in other amended plots (SW, PD and SS) by between 6.5-13%. At 20 Mg ha^{-1} application rates, SW amended soils had the highest SOM content of 24.8 g kg^{-1} and this was significantly higher than SOC content of PD (24.5 g kg^{-1}), SS (22.4 g kg^{-1})

Table 2: Soil organic matter (g kg^{-1}) content at the end of the study

	SOM content	
Amendments	1	2
No amendment	08.9	07.0
SS_{10}	20.0	21.4
SS_{20}	22.4	22.8
Mean	21.2	22.1
SW_{10}	19.8	19.3
SW_{20}	24.8	20.7
Mean	22.3	20.0
CD_{10}	20.7	20.0
CD_{20}	21.4	21.4
Mean	21.1	20.7
PD_{10}	21.7	18.6
PD_{20}	24.5	20.7
Mean	23.1	19.7
LSD 0.05		
Amendment (A)	0.025*	0.013*
Rate (R)	0.025*	0.0012*
A×R	0.046*	0.022*

*: Significant; 1, 2 = first and second cropping season

and CD (21.4 g kg^{-1}) in the first planting season. In the second planting season, SS amended plots with 22.8 g kg^{-1} SOM content had significantly higher SOM content than CD, SW and PD amended plots by between 6.1-9.2%. Cumulative results for the two seasons show that all plots amended with 20 Mg ha^{-1} waste rates had significantly higher SOM content than their corresponding 10 Mg ha^{-1} amendment rates by 4.8, 8.4, 10.6 and 14.0% for CD, SS, PD and SW amended plots, respectively.

However, although, statistical differences exist between the SOC contents of the waste amended plots and also the different rates of application, the magnitude of difference is low (between 4.6-13% for the amendments and 4-14% between the rates). These results show that several considerations should be made in choosing the kind of amendment for increasing the SOM content of soils.

On the average, the order of increase in SOM was PD> SW> SS>CD >C and SS> CD> SW> PD> C in the first and second planting seasons, respectively. The change in the order of SOM increase in the second planting season could probably be attributed to the decomposition and nutrient release by the wastes; since PD and SS decompose and release their nutrients faster than CD and SS (Mbah and Mbagwu, 2003). The increase observed in SOM content of waste amended plots could be as a result of higher levels of SOM in the wastes compared to the soil.

Effect of Organic Waste on Soil Carbohydrate Content

Table 3 showed that addition of wastes significantly ($p<0.05$) increased carbohydrate content of the soil. The level of increase depended on the type and rate of waste applied. At all rates, cold water extractible soluble carbohydrate values were lower than hot water and dilute acid extractible soluble carbohydrate content in both seasons. On the average, the concentrations of the dilute acid soluble carbohydrate were higher than cold water soluble carbohydrate by 354% (SS), 489% (SW), 692% (CD) and 676% PD in the first planting season. Similarly, percent increase in dilute acid soluble carbohydrate relative to the hot water soluble carbohydrate in the first season was 9% (SS), 20% (SW), 19% (CD) and 14% (PD). The carbohydrate concentration in waste amended soil was between 271-681 mg kg^{-1} (hot water-soluble), 56-281 mg kg^{-1} (cold water-soluble) and 330-821 mg kg^{-1} (dilute acid-soluble) in the first season. According to Bongiovanni and Lobartini (2006) the lower contents of carbohydrates extracted by cold water and hot water methods when compared to dilute acid extraction method were due to the fact that the dilute acid procedure extracted soluble carbohydrates plus also carbohydrates from hemicelulose, whereas hot water extraction failed to produce the hydrolysis of the hemicellulose.

Table 3: Effect of amendments on soil carbohydrate content (mg kg^{-1})

	1			2		
Amendments	Cold water	Hot water	Dil acid	Cold water	Hot water	Dil acid
No amendment	49.00	237.00	323.00	47.00	130.00	308.00
SS_{10}	79.00	345.00	392.00	167.00	247.00	394.00
SS_{20}	104.00	416.00	443.00	222.00	207.00	788.00
Mean	92.00	385.00	418.00	195.00	227.00	591.00
SW_{10}	56.00	484.00	583.00	64.00	147.00	486.00
SW_{20}	186.00	681.00	821.00	229.00	229.00	577.00
Mean	121.00	583.00	702.00	147.00	188.00	532.00
CD_{10}	56.00	336.00	364.00	50.00	135.00	552.00
CD_{20}	61.00	459.00	584.00	54.00	348.00	559.00
Mean	65.00	398.00	474.00	467.00	242.00	545.00
PD_{10}	89.00	271.00	330.00	133.00	142.00	391.00
PD_{20}	281.00	412.00	471.00	198.00	302.00	605.00
Mean	185.00	442.00	401.00	216.00	222.00	498.00
LSD 0.05						
Amendment (A)	2.756	166.34	4.074	2.132	1.451	02.315
Rates (R)	2.100	79.55	2.0218	2.065	0.841	03.332
A×R	3.862	15.61	5.015	3.764	1.840	05.712

Significant at $p = 0.05$, 1, 2 = First and second cropping season, respectively

The hot water extractible carbohydrate was mostly polysaccharides from plant exudates or microbial of origin (Haynes and Francis, 1993). Hot water soluble organic C makes up from 4-10% of the microbial biomass C. It also makes up about 6-8% of the total carbohydrate content in the soil. This pool is the most easily depleted of the three organic C pools (Haynes and Francis, 1993). In summary, it can be stated that the concentrations of OC, cold water, hot water and dilute acid extractible carbohydrates were all affected by the addition of the wastes. Soil carbohydrate content were also high in waste amended soil indicating 6-387, 4-168 and 30-1600% for cold water, hot water and dilute acid extractable carbohydrate, respectively in the second cropping season. Spaccini *et al.* (2004) found that waste management techniques were in some cases successful in increasing the carbohydrate content over that of control soil. They found an increase with alley-cropping, using *D. bacterii* either alone or in combination with *Pentaclethra* species at Umudike SE Nigeria, while at Nsukka also in SE Nigeria, with the lowest aggregate stability, intercropping with *C. cajan* and addition of rice mill waste and poultry manure also showed an increase of soil carbohydrate content.

Effect of Organic Wastes on Soil Aggregate Stability

The water-soluble aggregates significantly increased with increase in the rate of waste application (Table 4). At 20 Mg ha^{-1}, PD gave the highest increase of 33 and 56% in the first and second planting seasons, respectively. Aggregate stability values in waste amended plots ranged between 58.7-69 and 64-76.7% in the first and second planting seasons respectively. The values were 13.2-33.4 and 28.7-51.1% higher than the control in the first and second planting seasons, respectively. On the average, the order of improvement was PD > SW > CD > SS > CD. Aggregate stability values were lower in the first season than in the second planting season except in the control. The decrease was 5% (control) whereas on the average observed increase were 9.5% SS, 9.7% SW, 10% CD and 10% PD. Increases in aggregate stability of waste amended plots were between 14-33 and 30-56% in the first and second cropping seasons, respectively.

The increase in aggregate stability following waste addition could probably be due to the ability of the wastes to reduce the rate of wetting and enhance the resistance to stress generated during wetting as was observed by Quirk and Murray (1991), Rasaih and Kay (1995) and Caron *et al.* (1996). The aggregating efficiency of organic materials, however, is related to the decomposition of the material (Tisdall *et al.*, 1978).

Table 4: Effect of amendments on soil aggregates (WSA>0.25mm)

	Top soil (0-20 cm)	
Amendments	1	2
No amendment	51.70	49.30
SS$_{10}$	58.70	64.30
SS$_{20}$	64.00	70.70
Mean	61.50	67.40
SW$_{10}$	62.00	67.30
SW$_{20}$	66.70	75.30
Mean	64.90	71.00
CD$_{10}$	60.00	64.70
CD$_{20}$	66.00	71.00
Mean	62.30	68.50
PD$_{10}$	64.30	69.00
PD$_{20}$	70.30	76.70
Mean	66.70	73.50
LSD 0.05		
Amendment(A)	0.25*	0.260*
Rates (R)	0.46*	1.318*
A×R	1.075*	2.040*

*: Significant; 1, 2: First and second cropping season, respectively

Table 5: Relationship between aggregate stability and soil organic matter/carbohydrate content

Dependent parameter	Regression model	Co-efficient of variation (r)
Aggregate stability vs Organic matter	Y = 200.23-58.83x	0.688*
Aggregate stability vs Cold water soluble carbohydrate	Y = 076.93+0.058x	-0.123^{ns}
Aggregate stability vs Hot water soluble carbohydrate	Y = 055.84+0.281x	-0.243^{ns}
Aggregate stability vs dilute acid soluble carbohydrate	Y = 025.51+0.017x	-0.143^{ns}

Significant at p = 0.05; ns = Non significant

Relationship Between Organic Matter and Carbohydrate Pools with Aggregate Stability

The results showed that aggregate stability correlated positively with OM suggesting that OM plays an effective role in aggregating the studied soil (Table 5). Organic matter from wastes according to Mbagwu *et al.* (1991) bound smaller aggregates into larger ones which is essential for the production of good soil tilth.

Table 5 also showed that aggregate stability correlated poorly with soil carbohydrate pool. The low correlation values indicate that soil carbohydrate pool is not effective in aggregating this soil. In a study on the structural stability and carbohydrate content of an ultisol under different management system Adesodun *et al.* (2001) observed that soil carbohydrate pool does not promote aggregation of the soils. These findings (Adesodun *et al.*, 2001) agree with the observations of Igwe *et al.* (1995) but are in contrast with Caron *et al.* (1992) and Mbagwu and Piccolo (1998) which showed that carbohydrate participate in aggregate stability when they act in conjunction with humified SOM pools. Spaccini *et al.* (2001) observed that OC and acid-hydrolysable carbohydrates were reduced when tropical forested soils were cultivated and that neither of these constituents accounted for the differences in the aggregate stability of soils. They found a poor correlation between carbohydrates content and aggregate stability (MWD) in some tropical soils. Some workers have observed that the hot water extractable carbohydrate fraction in soils is more closely correlated with aggregate stability than total carbohydrate or organic C content (Haynes *et al.*, 1991; Angers *et al.*, 1993). Haynes and Beare (1997) elucidated that while both cold and hot water-extractable carbohydrate content showed a similar trend to aggregate stability under the non-legumes, plant growth had no measurable effect on either organic C or total carbohydrate content of soils. Haynes and Swift (1990) suggested that the hot water-extractable fraction represents extracellular polysaccharides mainly of microbial origin and that they are involved in the short-term stabilization of soil aggregates. The results of this study supports other findings suggesting that polysaccharides cannot be always considered as persistent structural stabilisers because of their rapid degradation by microbial activity (Insam, 1996 and Piccolo and Mbagwu, 1999).

CONCLUSIONS

The result of the study show that SOM contributes to soil aggregate stability. The structural stability of soils has impact on a wide range of processes that influence crop growth, soil erosion, runoff and the transport of contaminants from farmland to surface water bodies (Perfect *et al*., 1990). Information on the form and persistence of the aggregating constituents of SOM is vital particularly when dealing with fragile tropical soils, which are exposed to high risk of water erosion.

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