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WATER-STABLE AGGREGATES OF NIGER FLOODPLAIN SOILS AND THEIR ORGANIC CARBON, NITROGEN AND PHOSPHORUS DISTRIBUTION

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ABSTRACT

Five soil profiles were studied along a soil sequence in the Niger river floodplain to determine their soil properties and water-stable aggregates (WSA) between 4.75-2.00 mm, 2.00-1.00 mm, 1.00-0.50 mm, 0.50-02.5 mm and <0.25 mm. The relative distributions of soil organic carbon (SOC), total nitrogen and available phosphorus in water-stable aggregates, (WSA) were evaluated. Proximity to the river affected the SOC distribution within the WSA while the highest mean values of SOC were obtained from WSA 4.75-2.00 mm of profiles nearest to the river. The SOC correlated significantly with mean-weight diameter (MWD) (r= 0.61) and WSA class between 4.75-2.00 mm (r= 0.60). Higher C/N ratio of whole soils over the WSA classes was an indication of active mineralization of soil organic matter in the aggregates. The available phosphorus content of both the whole soil and the WSA classes is low, reflecting the low phosphorus contents of the parent materials, fixation and the redistribution of this element by erosion and flooding.

Key words: *Soil organic carbon, Water-stable aggregates, Floodplain, C/N ratio, Soil profile.*

INTRODUCTION

According to Tiessen (1999), the reliance of many developing countries on low-input production and increasing concern about the ecological impacts of excessive fertilizer or manure use led to the recognition of the important role of soil organic matter (SOM) and its associated nutrients in soil quality and fertility. In West Africa, Ahn (1979) reported the negative effects in terms of plant nutrient losses occurring during slash and burn practice associated with shifting cultivation in the area. The role of carbon, nitrogen and phosphorus in plant nutrition is enormous. Sanchez and Miller (1986) noted that soil organic matter played very important role in nutrient cycling in tropical ecosystems.

A number of researchers have discussed the distribution of SOM or fractions of SOM in water-stable aggregates and their role in aggregate stability (Aguilar and Heil, 1988; Buyanovsky et al., 1994; Angers and Giroux, 1996; Spaccini et al. 2001). In very warm, humid Northern Nigeria, Adamu et al. (1997) observed that the smaller aggregates were more enriched with soil organic carbon. Tisdall and Oades (1982) indicated the roles played by humus components in various soil aggregate sizes. However, Cambardella and Elliott (1993) reported that rapid changes in water-stable macroaggregation with cultivation under no-till, or with the introduction of a forage crop and manure application, have been associated with variations in labile soil organic matter (SOM) fractions such as particulate organic matter (POM). Aggregation especially at the macro level is very important for crop establishment, water infiltration and resistance to erosion and compaction (Angers and Giroux, 1996). In Nigeria and other parts of the tropics, the rate of soil organic matter losses due to high mineralization rate and nutrient losses due to soil erosion and leaching losses are high (Kang and Juo, 1981; Igwe, 2000). It is, therefore, very essential that these nutrients are conserved in these soils for sustainable productivity. Although there are some studies on distribution of SOC and other nutrients in WSA, yet none has discussed the distribution with respect to depth and the pedogenic implications

This paper, therefore, presents the results of study on the distribution of soil organic carbon (SOC), total nitrogen and phosphorus in fine-earth fraction (<2.0 mm) and water-stable aggregates in flood plain soil profiles on the lower course of river Niger, eastern Nigeria

Table 1: Some characteristics of the representative soil profiles

Horizon	Depth	Clay	Silt	Sand	MWD	pH		CEC
	(cm)	------------%--------			(mm)	H_2O	KCl	cmolkg^{-1}
Profile 1 (Typic Tropaquept or Dystric Fluvisol)*								
Ap	0-15	12	8	80	2.86	5.1	4.0	2.8
Bg1	15-30	20	6	74	1.16	4.9	3.9	3.5
Bg2	30-60	30	6	64	1.64	4.7	3.9	6.0
Bg3	60-93	22	4	74	0.47	5.1	3.9	6.9
BCg	93-130	20	4	76	2.97	4.9	3.8	3.9
Profile 2 (Typic Endoaquept or Dystric Gleysol)								
Ap	0-16	14	4	82	2.86	5.0	4.0	3.4
Bg1	16-37	18	6	76	2.28	5.2	4.0	5.7
Bg2	37-64	18	4	78	0.94	5.4	4.1	5.5
Bg3	64-108	16	4	80	0.74	5.5	4.1	5.4
Cg	108-175	6	2	92	1.17	6.0	4.2	2.5
Profile 3 (Dystric Durochrept or Dystric Gleysol)								
Ap	0-12	26	14	60	2.39	5.3	4.3	3.8
Bg1	12-27	34	10	56	1.98	5.5	4.4	3.0
Bg2	27-60	32	10	58	2.16	5.8	4.4	3.0
Bg3	60-80	34	12	54	1.42	5.8	4.2	4.1
Bg4	80-125	36	14	50	1.37	5.8	4.1	6.1
Profile 4 (Aquic Eutropept or Eutric Gleysol)								
Ap	0-20	18	20	62	2.73	5.6	4.8	6.2
Bg1	20-43	24	16	60	1.32	5.4	4.1	6.9
Bg2	43-79	24	16	60	1.08	5.6	4.1	8.0
Bg3	79-106	20	14	66	1.61	5.8	4.1	6.8
Bg4	106-160	24	10	66	0.68	6.1	4.1	6.7
Profile NFP/P5 (Fluvaquentic Eutropept or Eutric Fluvisol)								
Ap	0-23	12	18	70	0.72	5.7	4.9	6.1
AB	23-56	22	18	50	1.38	5.4	4.1	8.2
Bg1	56-84	22	20	58	1.79	5.6	4.2	7.8
Bg2	84-123	24	18	58	0.91	5.9	4.5	9.4
Bg3	123-170	16	16	68	0.67	6.0	4.7	6.7

*= Classification according to USDA Soil Taxonomy and FAO/UNESCO.

The objectives were, (i) to evaluate the concentrations of the SOC, total nitrogen and available P in soils and macroaggregates across profile depths and (ii) to relate the SOC contents to aggregate stability of the soils.

MATERIALS AND METHODS

Field Methods

The area is located between longitudes 6°42′ and 6°49′ E, latitudes 5°56′ and 6°03′ N. The floodplain covers an area of more than 15,000 km^2. All land units within the floodplain are below 30 m above sea level and with a slope gradient of between 0 and 1%. The mean annual bimodal rainfall is 1800 mm. It occurs from April to November and often with very high intensity (Obi and Salako, 1995). The mean monthly temperature is about 28℃. The vegetation is mainly derived savanna with some patches of rainforest. The soils are intensively cultivated with some root crops, rice and maize. Farmers raise the soils into big heaps of mounds to avoid waterlogged conditions. However, the flooded conditions are often utilized for paddy rice cultivation. Shifting cultivation is also practiced to allow the soil to regenerate. The underlying geological materials are mainly recent alluvial deposits (Orajaka, 1975).

Five soil profiles were sited in such a way that they represent different soil units on the sediments of the river Niger (Fig. 1). Soil profiles were sited on locations where there had been no cultivations for more than 5 years. The soil profile was described according to the method of FAO (1977) and the soils were identified as profiles 1, 2, 3, 4 and 5. Profile 5 was nearest to the river followed by profiles 4, 3 and 2 while profile 1 was nearest to the upland. Soil samples were collected from different pedogenic horizons, air dried and passed through 2.0 mm sieve and taken as a "whole soil".

Laboratory Methods

The method described by Kemper and Rosenau (1986) was used to separate water-stable aggregates. Fifty grams of the <4.75 mm air-dried soil were put in the topmost of four sieves of 2.00, 1.00, 0.50, and <0.25 mm and pre-soaked in deionised water for 30 min. Thereafter the nest of sieves and its contents were oscillated vertically in water 20 times at the rate of one oscil-

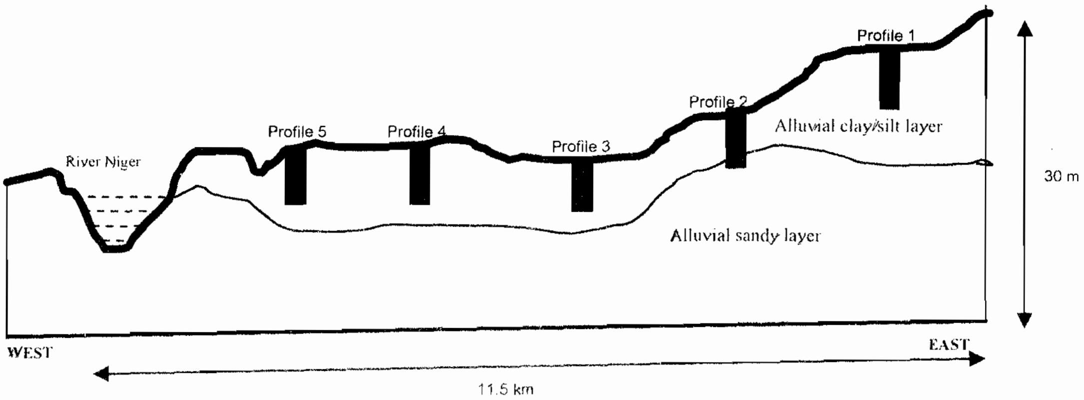

Fig. 1: Schematic diagram of soil profile locations

Table 2: Concentration of soil organic carbon (SOC) g kg^{-1} in water-stable aggregate (WSA) of the soil profiles in the floodplain.

Soil Depth (cm)	Whole Soil	Water-stable aggregate classes (mm)				
		4,75-2.00	2.00-1.00	1.00-0.50	0.50-0.25	<0.25
		Profile 1				
0-15	21.1	15.6	20.7	12.8	11,2	11.2
15-30	7.6	7.6	7.2	8.0	4.4	4.4
30-60	7.6	5.6	6.4	6.8	4.0	4.8
60-93	3.2	4.0	2.4	2.0	1.2	2.4
93-130	3.2	8.4	8.0	8.0	8.0	4.4
Mean	8.54	8,24	8.94	7.52	5.76	5.44
		Profile 2				
0-16	13.2	8.4	7.2	12.8	6.0	8.8
16-37	10.8	5.2	4.0	3.6	3.6	3.2
37-64	3.2	2.4	2.8	2.4	2.4	1.6
64-108	2.4	3.6	1.6	2.0	1.6	1.6
108-175	1.2	1.6	1.6	1.6	1.6	1.4
Mean	6.16	4.24	3.44	4.48	3.84	3.32
		Profile 3				
0-12	15.2	15.2	18.0	8.4	7.2	8.4
12-27	6.8	6.0	5.6	5.2	4.4	5.6
27-60	4.0	3.6	3.6	2.8	3.2	3.1
60-80	2.8	1.6	1.6	1.2	2.8	2.4
80-125	3.2	2.0	1.2	2.0	1.6	1.2
Mean	6.4	5.68	6.0	3.92	3.8	4.14
		Profile 4				
0-20	15.2	4.0	12.0	16.0	16.0	8.0
20-43	5.6	11.6	1.6	4.0	2.4	2.4
43-79	3.2	11.6	1.6	4.0	2.4	2.4
79-106	1.2	1.6	2.4	2.4	1.6	1.6
106-160	2.0	6.4	1.2	1.2	1.2	1.2
Mean	5.44	7.04	3.76	5.52	4,72	3.12
		Profile 5				
0-23	11.2	8.8	6.0	2.8	3.6	3.6
23-56	9.2	3.2	4.4	4.0	3.2	4.0
56-84	1,2	4.0	4.0	4.4	3.2	4.8
84-123	5.2	4.0	3.6	2.8	3.6	2.4
123-170	2.8	4.8	2.8	4.8	2.0	1.2
Mean	5.92	4.96	4.16	3.76	3.12	3.2

[a]=Fine-earth fraction <2.00 mm diameter

lation per second. After wet sieving, the resistant soil materials on each sieve and the unstable (<0.25 mm) aggregates were transferred into clean beakers, dried gently in the oven at 40° C for 48 h, weighed and stored for the determination of SOC, N and P. The percentage ratio of aggregates in each sieve represented the water-stable aggregates (WSA) of sizes 4.75-2.00 mm, 2.00-1.00 mm, 1.00-0.50 mm, 0.50-0.25 mm, and <0.25 mm after correction for sand content. The mean-weight diameter (MWD) of water-stable aggregates was calculated as

$$MWD = \sum_{i} X_i W_i$$

where, X_i is the diameter of the i^{th} sieve size and W_i is the proportion of the total aggregates in the i^{th} fraction. Higher MWD values indicate higher proportions of macroaggregates in the sample and therefore, higher stability.

Particle size distribution of <2 mm fractions was measured by the hydrometer method as described by Gee and Bauder (1986). The soil pH value was measured in 1:2.5 suspensions of soil in 0.1 M KCl and soil in deionised water. The cation exchange capacity (CEC) was determined using the ammonium acetate method buffered at pH 7 (Jackson, 1958). Organic carbon in both whole soil and water-stable aggregates (WSA) was determined by the Walkley and Black method as modified by Allison (1965). Total nitrogen in whole soil and WSA was determined by micro-Kjeldahl method (Bremner, 1965) while available phosphorus was determined by Bray II method described by Bray and Kurtz (1945) in both whole soil and WSA.

RESULTS

Soil Characteristics

Table 1 presents the major characteristics of the soils. They are medium to fine textured with more silt and fine sand in the soil profiles closest to the river. The soil pH is generally below 6.1 in water and 4.7 in KCl solution. Generally, the soils have low organic carbon content, and cation exchange capacity (CEC) with values often below 10 $cmol_c\ kg^{-1}$. They are classified as Entisols in the USDA Soil Taxonomy. In the FAO system, profiles 1 and 5 are classified as Fluvisols, while profiles 2, 3 and 4 are Gleysols (Table 1).Table 1: Some characteristics of the representative soil profiles

Water-stable aggregates and mean-weight diameter

Fig. 2 shows that in all the soil profiles, WSA 4.75-2.00 mm dominated the other aggregate size classes on the topsoil except the topsoil (0-23 cm) of profile 5. Aggregate size class (4.75-2.00 mm) was high in both 0-12 cm and the two immediate underlying horizons (12-27 and 27-60 cm) in profile 3. In the same soil profile the distribution of the other WSA classes were homogeneous except 2.00-1.00 mm classes. Apart from soils of horizon 56-84 cm depth in profile 5, the water-stable aggregate class 1.00-0.50 mm nearly dominated the WSA. As a result of the influence of alternate wetting and drying associated with seasonal flooding, the amount of water-unstable aggregate (<0.25 mm) increased in proportion relative to the water-stable aggregate sizes.

The mean-weight diameter (MWD) for the topsoil (0-20 cm) was highest on topsoil (0-20 cm) of profiles 1 to 4 respectively (Table 1). The lowest MWD was obtained in profile 5. The frequent deposition of sediments by the river on the land area of this soil profile may not have permitted the soil to mature and form stable aggregates that will resist deformation. In profiles 4 and 5, low MWD values were obtained towards Bg3 and Bg4 horizons.

Significant positive correlations were obtained between soil organic carbon (SOC), MWD (r=0.610) and water aggregate class 4.75-2.00 mm (r= 0.609). Also the water-unstable aggregates (<0.25 and 0.50-0.25 mm) showed negative significant correlation with SOC (r =-0.521 and –0.424). This shows the significant role of soil organic matter in the formation of stable aggregates in these soils. The organic matter content is low in these soils due to high mineralization rates and its depletion due to intensive agronomic activities.

Effects of flooding incidents on soil organic carbon (SOC) distribution

Generally, very high values of soil organic carbon (SOC) were recorded on all the topsoil [11.2-21.0 $g\ kg^{-1}$], (Table 2). These values decreased with soil depth in profiles 1 and 2. In profiles 3 and 4, there was also a decrease in SOC with depth. The high occurrence of

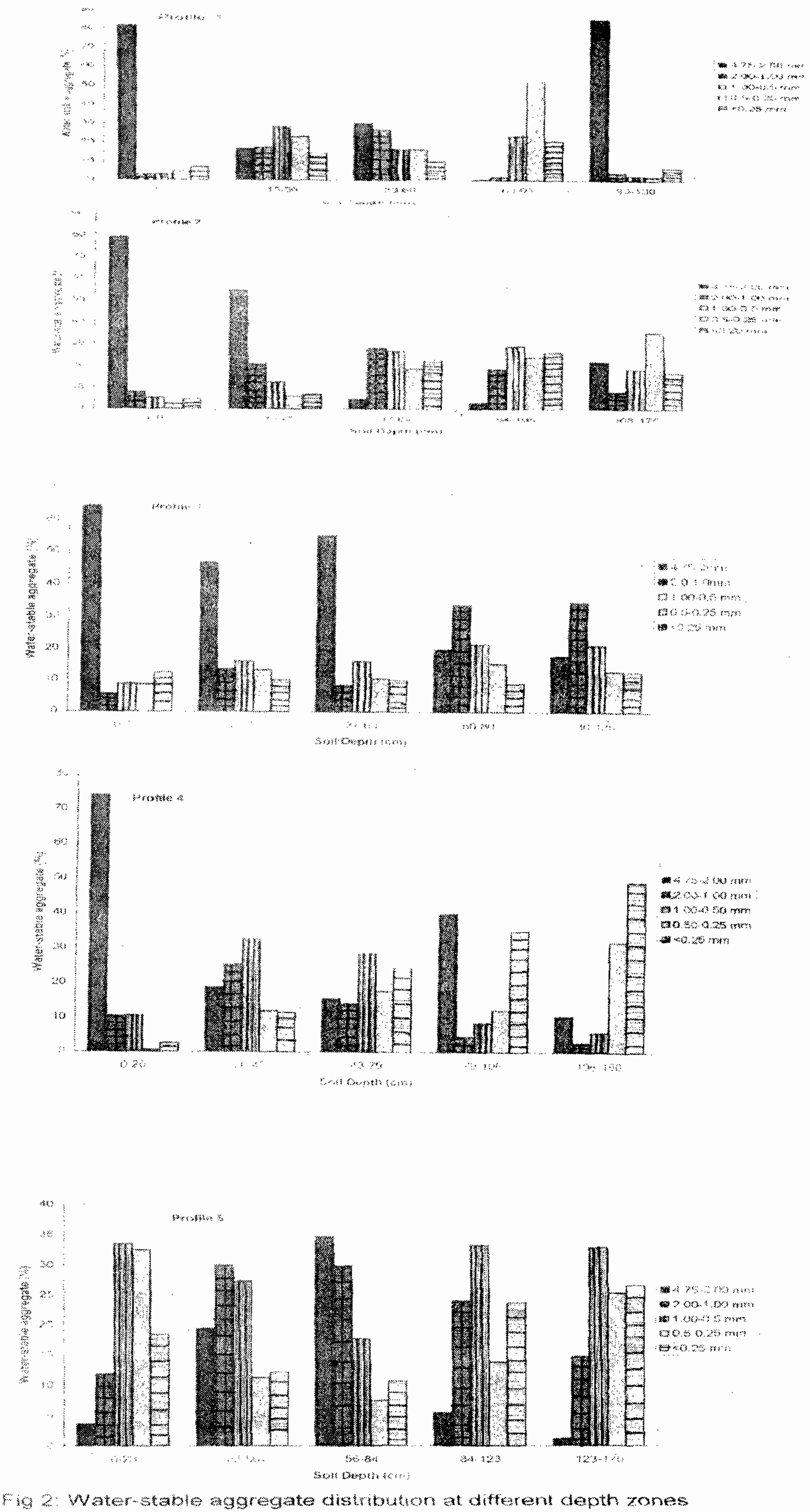

Fig 2: Water-stable aggregate distribution at different depth zones in soil profiles

Table 3: Concentration of total nitrogen (TN) g kg^{-1} in water-stable aggregate (WSA) of the soil profiles in the floodplain.

Soil Depth (cm)		Water-stable aggregate classes (mm)				
	Whole Soil	4.75-2.00	2.00-1.00	1.00-0.50	0.50-0.25	<0.25
			Profile 1			
0-15	1.5	1.0	1.0	1.0	0.9	0.9
15-30	0.6	0.7	0.6	0.7	0.4	0.4
30-60	0.5	0.5	0.6	0.6	0.4	0.4
60-93	0.2	0.4	0.2	0.2	0.1	0.2
93-130	0.2	0.8	0.8	0.8	0.8	0.4
Mean	0.6	0.66	0.64	0.65	0.52	0.47
			Profile 2			
0-16	0.9	0.8	0.7	nd	nd	nd
16-37	0.6	0.5	0.4	0.3	0.3	nd
37-64	0.3	0.2	0.2	0.2	0.2	0.2
64-108	0.2	0.3	0.1	0.2	0.1	0.1
108-175	0.1	0.1	0.1	0.1	0.1	0.1
Mean	0.4	0.37	0.31	0.16	0.15	0.14
			Profile 3			
0-12	1.0	1.0	1.0	0.8	0.7	0.8
12-27	0.5	0.6	0.5	0.5	0.4	0.5
27-60	0.3	0.3	0.3	0.3	0.3	0.3
60-80	0.2	0.1	0.1	0.1	0.3	0.3
80-125	0.2	0.2	0.1	0.2	0.1	0.1
Mean	0.4	0.43	0.41	0.37	0.35	0.39
			Profile 4			
0-20	1.0	0.4	0.9	0.9	1.0	0.8
20-43	0.4	0.9	0.1	0.4	0.2	0.2
43-79	0.2	1.0	0.1	0.4	0.2	0.2
79-106	0.1	0.1	0.2	0.2	0.1	0.1
106-160	0.1	0.6	0.1	0.1	0.1	0.1
Mean	0.4	0.6	0.28	0.40	0.32	0.28
			Profile 5			
0-23	0.9	0.9	0.6	0.3	0.4	0.3
23-56	0.6	0.3	0.4	0.4	0.4	0.4
56-84	0.1	0.4	0.4	0.3	0.3	0.4
84-123	0.2	0.4	0.3	0.3	0.3	0.2
123-170	0.2	nd	0.3	0.40	0.2	0.1
Mean	0.4	0.4	0.4	0.34	0.30	0.30

nd = not determined

SOC in the topsoil may be as result of seasonal deposition of organic material by flooding and the rapid decomposition of deposited plant remains *in situ*. These occur annually thus enriching the topsoil with soil organic carbon.

There was an abrupt decrease in SOC with depth at horizon 56-84 cm in profile 5, and an increase of low magnitude in the underlying (84-123 cm) horizon. This phenomenon is common in soils developed on river sediments with varying organic matter contents within the sediments deposited at different times. Profile 5 that is closer to the river than the other soil profiles and most affected by the flooding has the least SOC, while profile 1 has the highest SOC on the topsoil. The reason for this may be due to the coarse mineral materials deposited nearer the river while the finer materials including finer organic materials are moved and deposited farther away towards the area of profile 1. The highest mean SOC values were recorded for profile 1 and followed by those of profiles 3 and 2 respectively. Lower mean values of SOC were obtained for profiles 4 and 5. Although these values are not statistically significant, they showed some trend in the distribution of SOC within the soil profile.

Distribution of soil organic carbon (SOC) and total nitrogen in water-stable aggregates

Soil organic carbon (SOC) concentrations in water-stable aggregates (WSA) of the profiles varied with soil and proximity to the upland or the river (Table 2). In profiles 1 and 3, the highest SOC value was obtained from 2.00-1.00 mm and 4.75-2.00 mm aggregate classes. The SOC in profile 2 was highest in 1.00-0.50 mm aggregate size class, followed by 4.75-2.00 mm class. The WSA 4.75-2.00 mm has the highest mean values of SOC in profiles 4 and 5.

The highest values of total nitrogen were

Table 4: Carbon/nitrogen (C/N) ratio in water-stable aggregate (WSA) of the soil profiles in the floodplain.

Soil Depth (cm)	Whole Soil	Water-stable aggregate classes (mm) 4.75-2.00	2.00-1.00	1.00-0.50	0.50-0.25	<0.25
			Profile 1			
0-15	14	16	21	13	12	12
15-30	13	11	11	11	11	11
30-60	15	11	11	11	11	12
60-93	14	11	13	13	12	12
93-130	16	11	11	11	11	12
Mean	10	12	13	12	11	12
			Profile 2			
0-16	15	10	9	-	-	-
16-37	18	11	11	11	11	-
37-64	13	12	13	12	12	8
64-108	12	13	12	13	12	13
108-175	12	16	16	16	15	16
Mean	14	12	12	13	13	12
			Profile 3			
0-12	16	16	18	11	10	11
12-27	15	11	11	10	12	11
27-60	15	11	11	9	11	10
60-80	19	13	13	12	11	8
80-125	16	11	12	11	13	12
Mean	16	12	13	11	11	10
			Profile 4			
0-20	16	11	14	16	16	11
20-43	15	13	16	11	13	12
43-79	14	12	16	11	13	12
79-106	12	15	11	12	11	11
106-160	20	11	10	11	11	12
Mean	15	12	13	12	13	12
			Profile 5			
0-23	12	10	11	11	10	11
23-56	16	10	11	10	9	11
56-84	12	10	10	13	9	11
84-123	11	11	11	9	11	10
123-170	18	-	9	11	13	9
Mean	14	10	10	11	10	10

obtained in the whole soils of profile 1 compared to the other profiles (Table 3). The average total nitrogen distribution in the water-stable aggregates is shown (Table 3). In profile 1, the highest mean value of total nitrogen was obtained from 4.75-2.00 mm, and 1.00-0.50 mm WSA classes. The aggregate bound total nitrogen are higher in larger than the fine aggregates. In profile 2, the arrangement was 4.75-2.00 > 2.00-1.00 > 1.00-0.50 > 0.50-0.25 > less than 0.25 mm classes. In profile 4 the aggregate bound total nitrogen concentration fluctuated within the aggregates. The value was highest in 4.75-2.00 mm aggregate size followed by 1.00-0.50 mm aggregate sizes. The WSA bound total nitrogen values in profile 5 did not differ (Table 3).

Higher carbon/nitrogen (C/N) ratio was obtained in the whole soil samples than the water-stable aggregate fractions (Table 4). The C/N ratio of WSA was below 13 in all the profiles, indicating high mineralization process within the aggregates.

Distribution of available phosphorus in water-stable aggregates (WSA)

Generally, higher values of available phosphorus were obtained in the whole soils than in the water-stable aggregate classes (Table 5). The mean values of available phosphorus in the whole soils are higher in the soils nearest to the river than those of the upland. This may be caused by the influence of the parent material (mud clay and river sediments) and the flooding incidence experienced annually within the land units of these profile closer to the river.Table 5:Concentrations of soil available phosphorus mg kg^{-1} in water-stable aggregate (WSA)

of the soil profiles in the floodplain

DISCUSSION

The emphasis of this study is on the distribution of aggregate bound soil organic carbon, total nitrogen and

Table 5: Concentrations of soil available phosphorus mg kg^{-1} in water-stable aggregate (WSA) of the soil profiles in the floodplain

Soil Depth (cm)		Water-stable aggregate classes (mm)				
	Whole Soil	4.75-2.00	2.00-1.00	1.00-0.50	0.50-0.25	<0.25
		Profile 1				
0-15	12.0	6.6	6.6	6.6	5.8	nd
15-30	9.6	5.8	5.1	5.1	3.7	4.4
30-60	8.4	5.1	4.4	5.1	5.1	4.4
60-93	9.6	nd	nd	5.8	4.4	3.7
93-130	12.0	nd	8.0	6.6	nd	nd
Mean	10.3	5.8	6.0	5.8	4.8	4.2
		Profile 2				
0-16	10.8	5.0	6.7	5.0	nd	nd
16-37	12.0	4.2	4.2	4.2	4.2	nd
37-64	9.6	3.4	3.4	3.4	5.0	4.2
64-108	8.4	5.0	3.4	4.2	3.4	2.5
108-175	13.2	3.4	3.4	3.4	3.4	3.4
Mean	10.8	4.2	4.2	4.0	4.0	3.4
		Profile 3				
0-12	14.4	7.6	5.0	5.0	5.9	5.0
12-27	12.0	4.2	3.4	3.4	3.4	3.4
27-60	13.2	3.4	4.2	4.2	4.2	3.4
60-80	13.2	4.2	4.2	2.5	4.2	4.2
80-125	14.4	4.2	4.2	5.0	3.4	5.0
Mean	13.4	4.7	4.2	4.0	4.2	4.2
		Profile 4				
0-20	26.4	3.4	4.2	5.0	5.0	5.0
20-43	14.4	5.0	2.5	3.4	3.4	3.4
43-79	13.2	5.0	2.5	3.4	3.4	3.4
79-106	10.8	4.4	3.7	5.8	3.4	5.8
106-160	12.0	5.8	nd	5.8	5.8	5.8
Mean	15.4	4.7	3.2	4.7	4.2	4.7
		Profile 5				
0-23	18.0	5.0	3.4	3.4	3.4	4.2
23-56	16.0	4.2	4.2	4.2	3.4	4.2
56-84	21.6	4.2	4.2	4.2	4.2	4.2
84-123	13.2	6.7	6.7	5.9	5.0	5.9
123-170	12.0	nd	5.0	5.0	5.0	4.2
Mean	16.2	5.0	4.7	4.5	4.2	4.5

nd = Not determined.

available phosphate, which are depleted when soil erosion and excessive runoff due to flooding and excessive cultivation in this agro ecological zone. This is in realization that the depletion of SOC, total N and available P affects significantly the agricultural production in this zone of low input agriculture. The role of soil organic matter (SOM) in low input sustainable agriculture must be understood within the framework of controls on ecosystems, interactions between the components of ecosystems and the processes controlling these interactions. (Elliott et al., 1993; Feller (1993) outlined various environmental factors that determine organic matter contents and variations in tropical soils. These include rainfall, erosion, hydromorphology and soil texture. In the study area, hydromorphology in terms of seasonal flooding resulting to water logging may have exerted greatest influence on the aggregate size distribution and the SOC within the aggregate sizes. Thus the trend is the modifications of aggregates through thixotropic age hardening of the aggregates and also the modifications of the aggregates by alternate wetting and drying. Caron et al., (1992) discussed the relative improvement of structural stability of a clay loam with alternate wetting and drying. The slaking that tends to occur in these soils when wet reverses tremendously upon drying.

The higher values of SOC in the whole soil and WSA classes over the water-unstable aggregates are indications of the positive influence of SOC on the stability of these aggregates. The hydrophobic bonding of SOC in the WSA classes can be used to explain the resistance of the aggregates to slaking even under long period of submergence in water. Piccolo (1996) explained the beneficial contributions of the hydrophobic bonding of SOC in soils. Also Igwe et al., (1999) showed that SOC contributes significantly to macroaggregate stability in some soils of the tropics irrespective of their proportions in the soil.

The higher C/N ratio of the whole soils over the WSA aggregate classes in most soils indicated the abundance of raw organic matter that is less decomposed than in the WSA. Buyanovsky *et al.*, (1994) obtained narrow C/N ratio in smaller WSA classes (aggregates <0.50 mm) with higher clay contents. They attributed this to less rapid turnover of SOC in small aggregates, which indicated that their organic matter was relatively complex and might include carbon with residence time extending to 10 or more years. The results of C/N ratio obtained for whole soils are typical of most West African soils under flooding condition. In West Africa the C/N ratio of most soils are narrow even under submerged condition (Feller 1993). Ahn (1979) indicated that this narrow C/N ratio of soils and aggregates signified high mineralization rate occurring in them. This is supported by high temperature of the surrounding environment that aids mineralization generally in the tropical region.

Differential available phosphorus obtained in whole soils and the WSA may have occurred due to some factors such as phosphate fixation and slow release of of this nutrient in the soil. Aguilar and Heil (1988) observed that variations in phosphorus content along a toposequence reflected changes in parent material and redistribution of sediments by erosion. In the WSA classes the concentration of available phosphorus was not significantly different and reflects the values of available phosphorus in the whole soil. Soils of eastern Nigeria are generally low in available phosphorus (Enwezor, 1977). This is due to high fixation rate of the soils and also low phosphorus contents of the parent material.

In conclusion, these results show that flooding may have affected significantly the distribution of water-stable aggregates and the aggregate bound SOC, total nitrogen and available phosphorus contents of the aggregate classes. The SOC contents are very important in the protection of these aggregates from deformation from environmental factors such as erosion and hydromorphology.

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