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Dynamics of Sediment Organic Matter along Bandama River in the Department of Sinématiali, Northern Côte d'Ivoire

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study examines the distribution of organic matter in areas affected by frequent floods along the east bank of the Bandama River in the department of Sinématiali. The sites sampled are defined by two zones, one near the stream and one far from the stream. Samples collected were analyzed, including for texture with aggregation analysis by the Robinson pipette, and standard sediment analysis methods for measuring organic carbon (CO), nitrogen (N), and organic matter (MO). Statistical analyzes were carried out to assess the differences between the physico-chemical parameters of the different sampling areas. Results show that sediment from the various study sites has a sando-limonous to limono-clay texture. Total organic matter levels are higher in surface sediments that contain the lowest proportions of clay. Rates range from 31.98 gkg-1 to 38.98 gkg-1. In depth, the rates obtained are very low and range from 6.3 gkg-1 to 8.193 gkg-1. The low rates recorded in depth are reported to be related to leaching caused by periodic flooding. These results show that successive floods have a direct effect on the dynamics of the physico-chemical properties of the sediments along the shore.

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1. INTRODUCTION

During the past decade, the number of studies on the effects of climate change on the environment has increased steadily. One of the potential impacts of climate change on the water cycle is an increase in the number and intensity of floods [1,2,3]. At present, it is important to quantify the impact of climate change on the river environment in order to better understand how these environments will evolve in the coming decades. Riparian ecosystems vary widely depending on river dynamics [4]. The constant supply of sediment transported by successive floods has an impact on the physico-chemical properties of soils. The latter can vary greatly in vertical distribution and spatial distribution, which are affected by various hydrological processes [5,6]. Sediment is a relatively heterogeneous matrix consisting of water, inorganic and organic materials and anthropogenic compounds. It can be described by its composition and structure [7] (Power and Chapman. Surface sediments are among the most important storage and dynamic reservoirs of organic matter [8]. Each year, nearly 0,4 Gt of terrestrial organic carbon is transported to coastal environments [9]. MO consists of a large number of chemical species that may be of size, chemical composition, and complex and varied physical forms [10]. These different parameters will depend primarily on the origin but also on the environment in which the MO will be located [11]. MO is a complex substance consisting primarily of carbon and hydrogen and in variable proportions of oxygen, nitrogen, sulfur and phosphorus [11]. Nitrogen and organic carbon play very important roles in MO biogeochemistry [12] particularly in microbiological activity [13] and metal complexation processes [14]. The study of sedimentary organic matter in current environments could be used as a basis for paleoclimatic, and paleoenvironmental interpretations [15]. Previous work indicates little information on the distribution of these physico-chemical parameters in sediments along Bandama River shore. As a result, this study will attempt to highlight the impact of recurring flooding on sediment organic matter in this area. The aim is to assess the levels of organic matter in sediments away from the stream and compare them with those in the surrounding environment in order to highlight the impact of the floods on the river environment. No studies were conducted on sediment organic matter along the rivers of this region. The main purpose of this study is to address this shortcoming. To carry out this work, a multidisciplinary approach has been taken. It is based in particular on sedimentological and pedological studies.

2. MATERIALS AND METHODS

2.1 Location and Sampling

Four sampling points along the shore were predefined (Fig. 1) and were sampled from surface sediments at a depth of 10 to 150 cm. The various analyzes carried out in this study were carried out on the fine length part (< 2 mm), which we separated at the laboratory a few weeks later after sampling.

These samples were analyzed to determine:

- The particle size (sandy, clay and lemon fraction), pH, total organic carbon, total nitrogen and organic matter.

- The analysis of each of these parameters involved specific methods as described in Fig.1.

2.2 Physico-chemical Characterization of Sediment

2.2.1 Physical parameters of sediments

2.2.1.1 Granulometry

It was determined by Robinson's Pipette method [16].

The application of this analysis allowed:

- To know the substances (MO and nitrogen) associated with the particle size contained in the sediment. It is used to determine whether they are in the fine, medium or coarse fractions;

- To reconstitute the conditions for transport and deposition of particles.

2.2.1.2 Texture

We used the triangular diagram of fine soils proposed by [17]. This type of diagram is particularly suitable for sediments because sediments can then be characterized according to the respective content of these three particle size fractions (clays, silt and sand) [18,19].

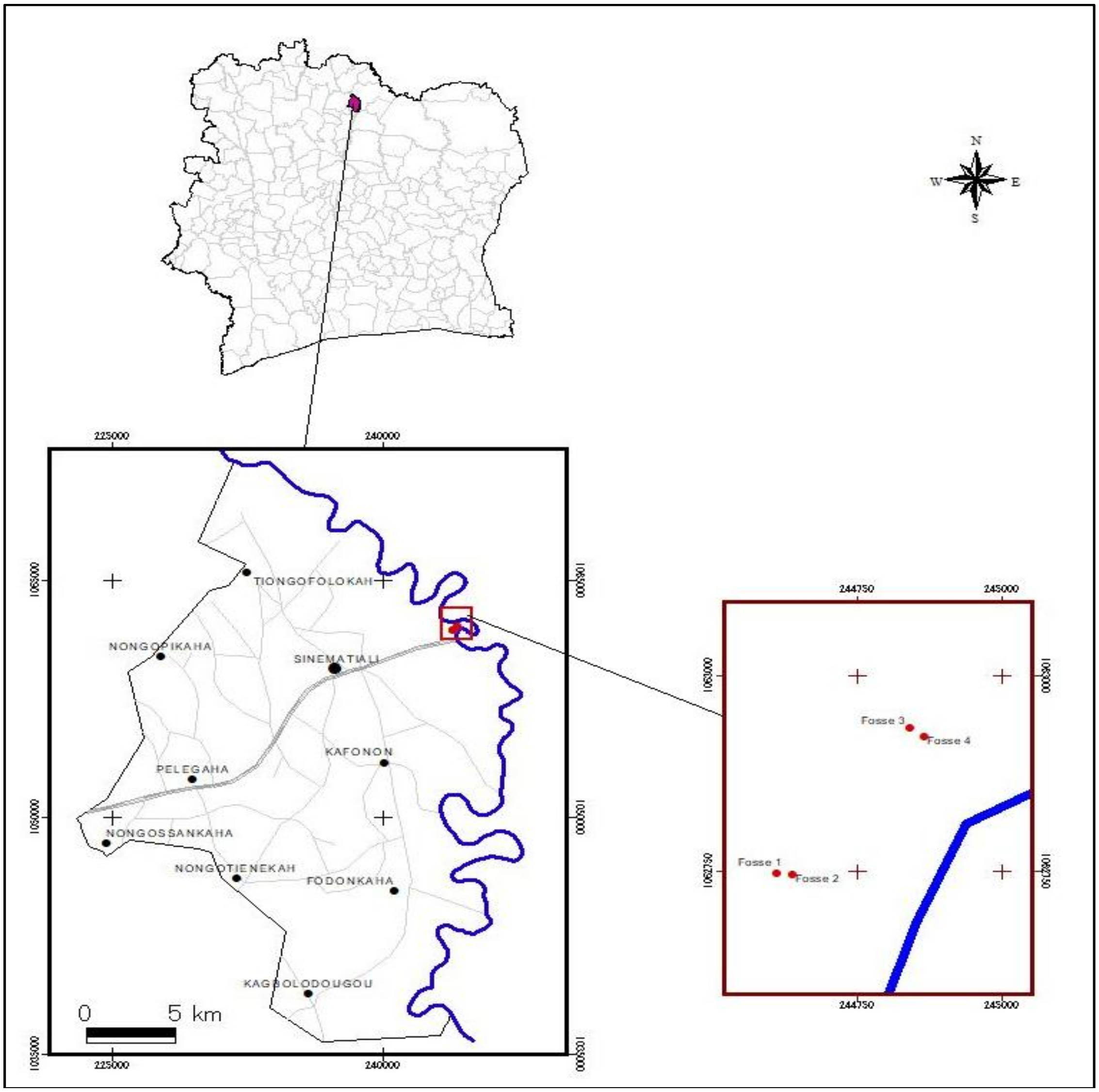

Fig. 1. Location Map

2.2.2 Chemical sediment parameters

On the same samples we also determined CO, MO, nitrogen and PH levels.

pH: pH of water was determined by measuring H3O+ ion activity using a pHmeter [20].

Organic carbon: Organic carbon of sediments is determined by Anne's method [21]. The carbon of the organic matter is oxidized by potassium bichromate in sulfuric medium.

2.2.2.1 Organic matter

The assessment of the organic matter content was made by quantifying its major constituent element, organic carbon, which represents almost 50% of this element [22]. The content of the MO was assessed based on the following conventional relationship: MO= C×1,72 [23].

2.2.2.2 Nitrogen

Nitrogen in sediments was determined by the Kjeldahl method [20]. The principle of this method is to transform the nitrogen of organic compounds from a finely crushed sediment sample into ammoniacal nitrogen under the action of concentrated sulfuric acid, which, when boiled, behaves as an oxidant. Organic substances are decomposed: Carbon comes out as carbon dioxide, hydrogen gives water and nitrogen is transformed into ammonia nitrogen. The latter is fixed immediately by sulfuric acid in the form of ammonium sulfate.

2.2.2.3 Carbon-to-Nitrogen Ratio (C/N)

The C/N ratio is an indicator of sediment biological activity that provides information on the degree of organic matter evolution, biological activity, mineralization. The smaller the biological activity, the more difficulties encountered in mineralization. This reflects conditions of anaerobic, excessive acidity. The study of the C/N report is an approach to the problem of the origin, nature and evolution of organic matter [24].

2.2.3 Statistical analysis

For data analysis, we used variance analysis of different variables using SAS 9.4 software. The significance test is Fischer's distribution or "F test" at the 5% probability threshold. Correlation tests (Pearson) were also performed between variables (MO, pH, C.O., N, texture). These tests allowed comparisons of different parameters according to the horizontal gradient (channel distance) and vertical (depth). Finally, a primary component (PCA) analysis was conducted to verify that there is a link between the different physico-chemical parameters, the layers and the positions close to or far from the stream. We converted the units of % to gkg-1 (international unit) for carbon, nitrogen and organic matter (MO).

3. RESULTS

3.1 Sediment Granulometry and Texture

The clay fraction increases with depth in the profile near the stream bed (Fig. 2). The remote profile of the source has similar characteristics. Limon percentages decrease with depth near the channel while sand percentages increase. The sandy fraction is greater when you move away from the channel. Sediments are coarser by moving away from the stream (Figs. 2 and 3). Sediments near the river are characterized by higher percentages in silt. The results of our analyzes reveal a limono-clay texture near the channel and a sandy-clay texture as one moves away from the channel (Table 1).

3.2 Chemical Parameters

3.2.1 pH

The pH of the sediments relative to their stream position. Sediments have low acidity pH ranging from 5.72 to 5.79 (Fig. 4). This low acidity could be explained by the absence of abundant surface litter in this area. Decomposition of litter and humus releases acidifying products such as fluvial and humic acids that acidify surface sediments.

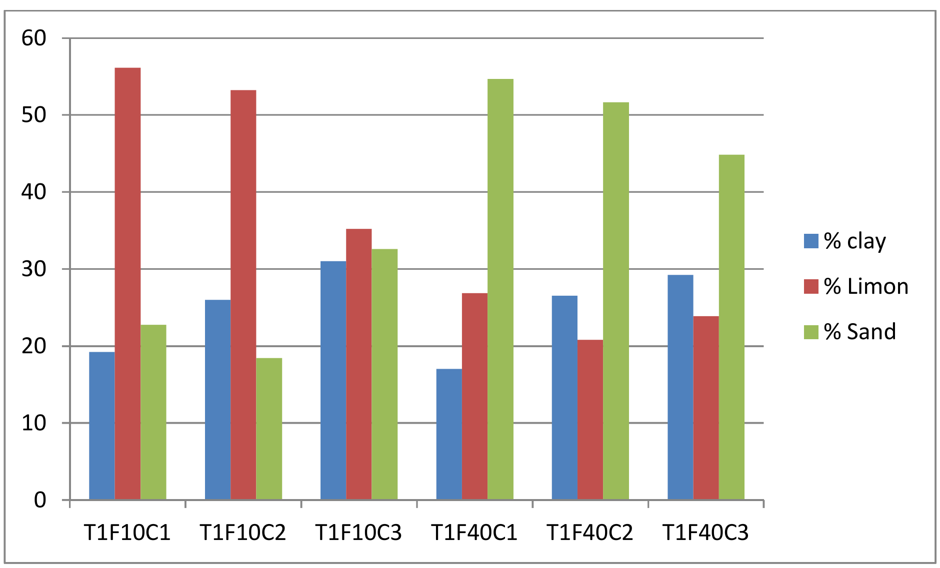

Fig. 2. Particle size composition
F10 = pit near the river F40 = remote pit

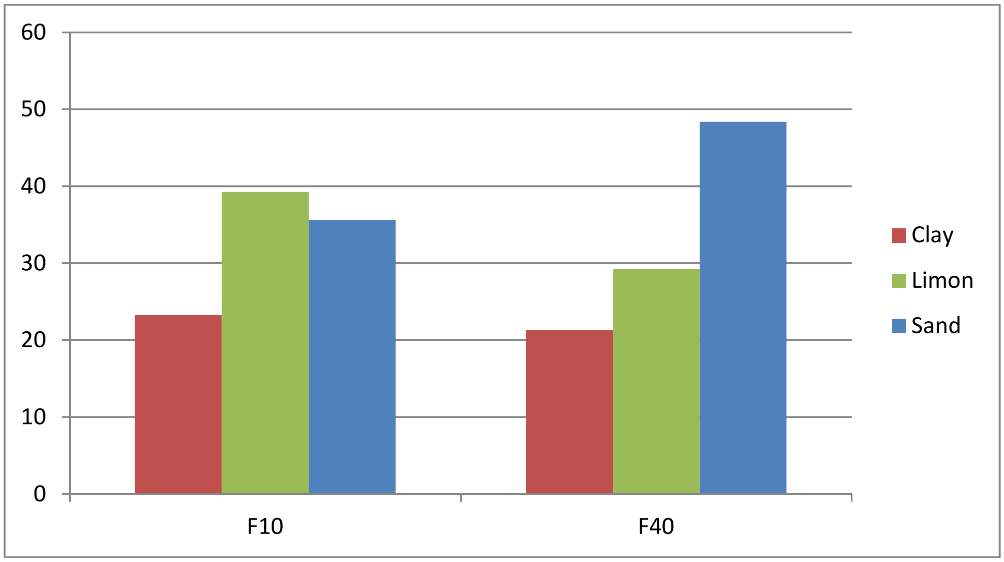

Fig. 3. Granulometry relative to profile positioning

Table 1. Granulometry and sediment texture of layers according to positions

Layer	$F10_1$	$F10_2$	$F10_3$	$F40_1$	$F40_2$	$F40_3$
Coarse sand (p.c.)	5,55	5,25	24,95	16,95	17,55	14,75
Fine sand (p.c.)	17,2	13,15	7,65	37,7	34,1	30,1
Coarse Limon (p.c.)	42,65	44,2	24,2	16,35	12,55	16,15
Fine Limon (p.c.)	13,5	9	11	10,5	8,25	7,75
Clay (p.c.)	19,25	26	31	17	26,5	29,25
Texture	LS	LA	LA	SL	SA	SA

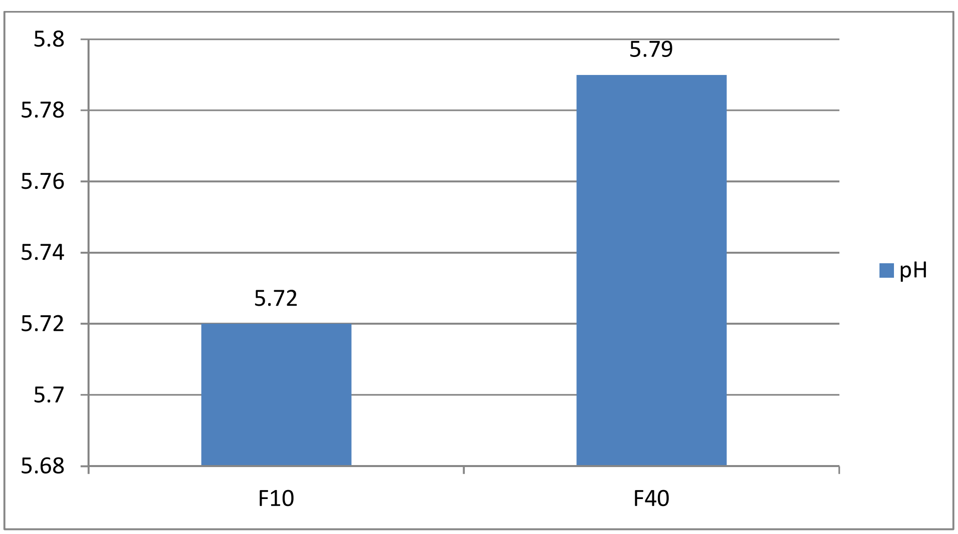

Fig. 4. Change in pH by position

3.2.1.1 Change in pH in different layers

A change in the pH value from the surface to the depth is noted (Fig. 5). Biomass is often almost non-existent in depth and therefore very little input from acidifying products. This could explain the high pH value in the depth layers.

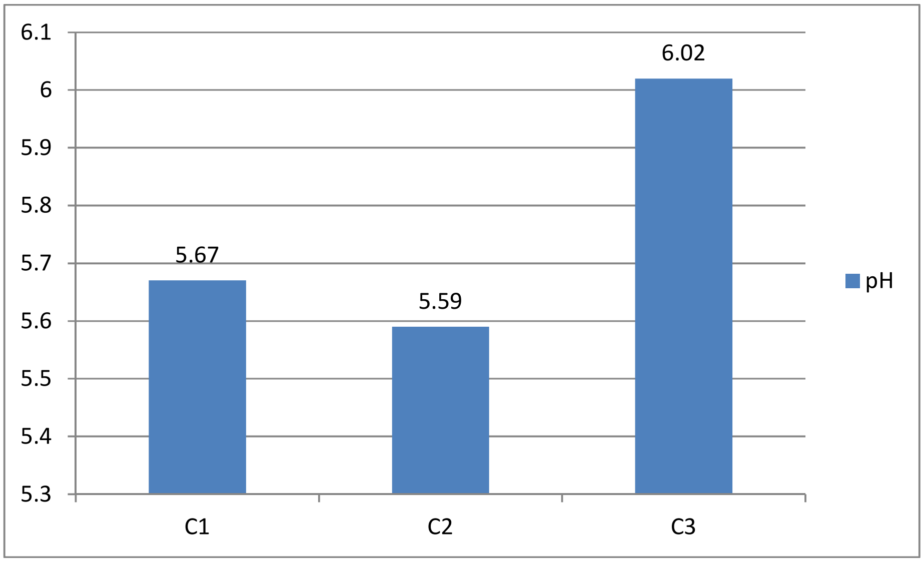

Fig. 5. Variation in layers

3.2.2 Organic matter

3.2.2.1 Change of MO in pits to position

Organic matter does not vary significantly from pit position (Fig. 6). These values indicate relatively lower rates in areas far from the stream. Concentrations ranging from 21.01 to 18.21 (gkg-1) indicate medium-rich organic sediment [25].

3.2.2.2 Change in MO in layers

Analyzes show a sharp decrease in organic matter content when going deep (Figs. 6 and 7). The MO rate increases from 38.98 gkg-1 on the surface to 8.19 gkg-1 deep when close to the stream. Further away from the watercourse, surface rates are 31.73 gkg-1 and depth rates are 6.3 gkg-1.

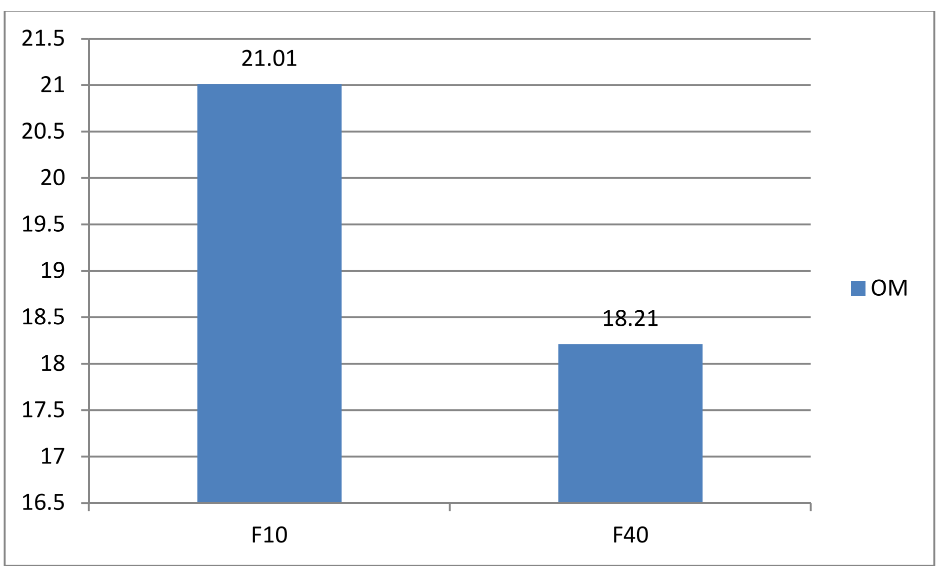

Fig. 6. Change in organic matter content by position

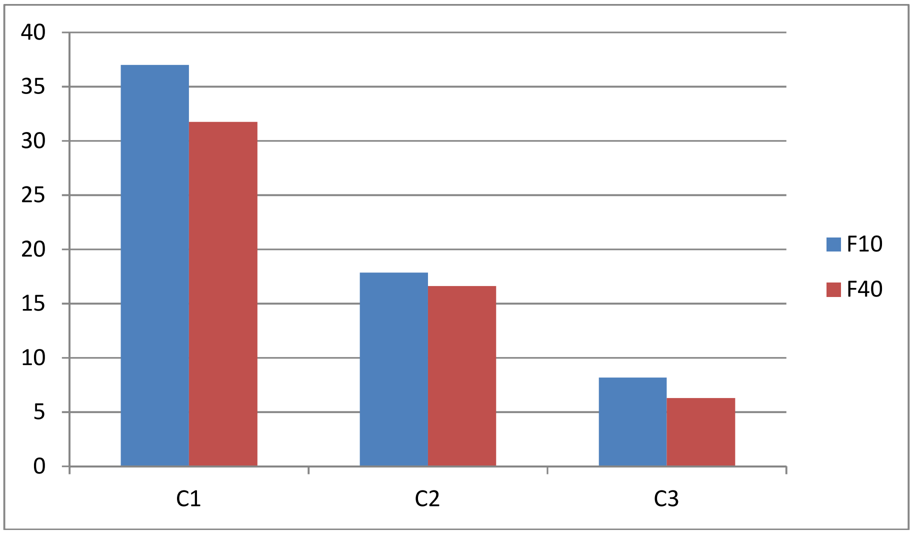

Fig. 7. Change in MO content in layers by position

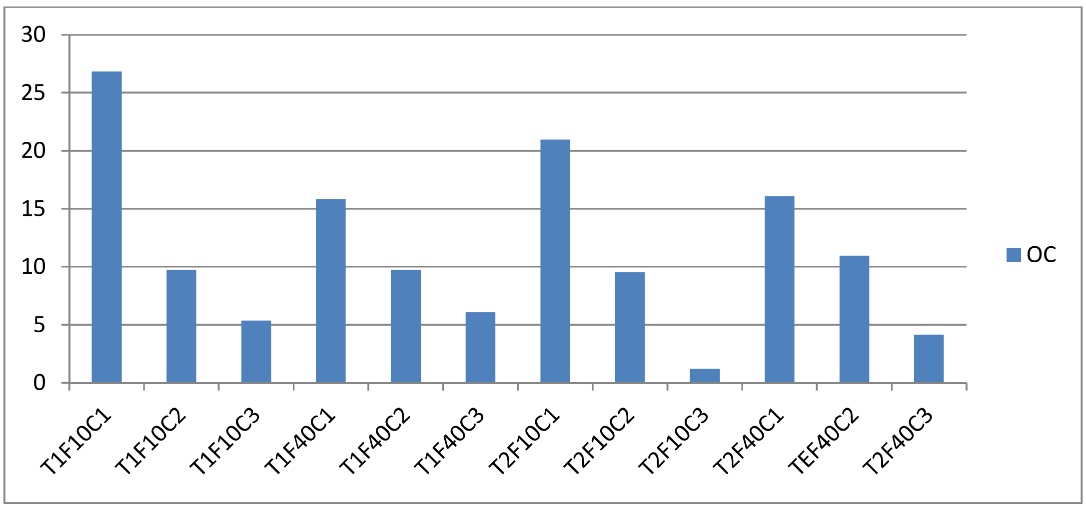

Fig. 8. Change in CO in transects and layers relative to profile position
F10= Close Fosse F40= Fosse distant

3.2.3 Organic carbon

The results of our investigations show a decrease in organic carbon in all pit areas at the base of the profile (Fig. 8). However, it is noted that this organic carbon is slightly elevated at the surface layer level. For remote pits it would be the lack of plants on the ground and therefore the absence of litter. Generally, reduced organic matter intake in soil directly influences low organic carbon levels in the different profile horizons [26].

3.2.4 The nitrogen

Analyzes show that nitrogen has approximately the same evolution in the profiles as organic carbon and organic matter (Fig. 9). This suggests a correlation between these three elements.

3.2.5 Report C/N

Analytical results indicate a decrease in C/N ratio with depth near the stream (Fig. 10). This ratio ranges from 20.81 to 7.25. Biological activity in sediments is therefore reduced and organic matter decomposition is slowed. In addition, this ratio increases slightly with depth for the remote layers of the stream. Values range from 20.20 to 24.66. The slight increase in C/N in the deep layers reflects faster degradation of nitrogen compounds.

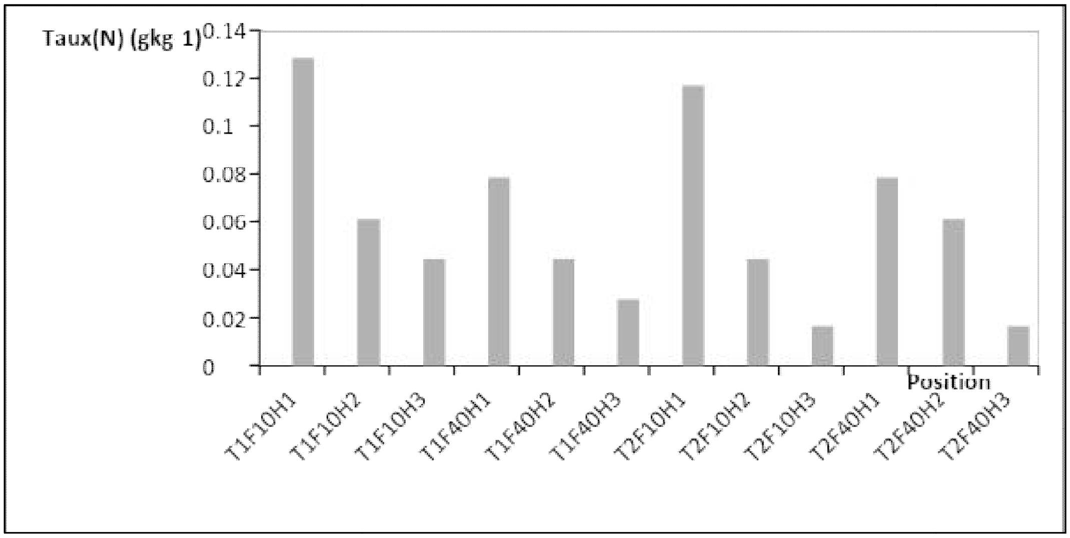

Fig. 9. Changes in nitrogen levels in layers

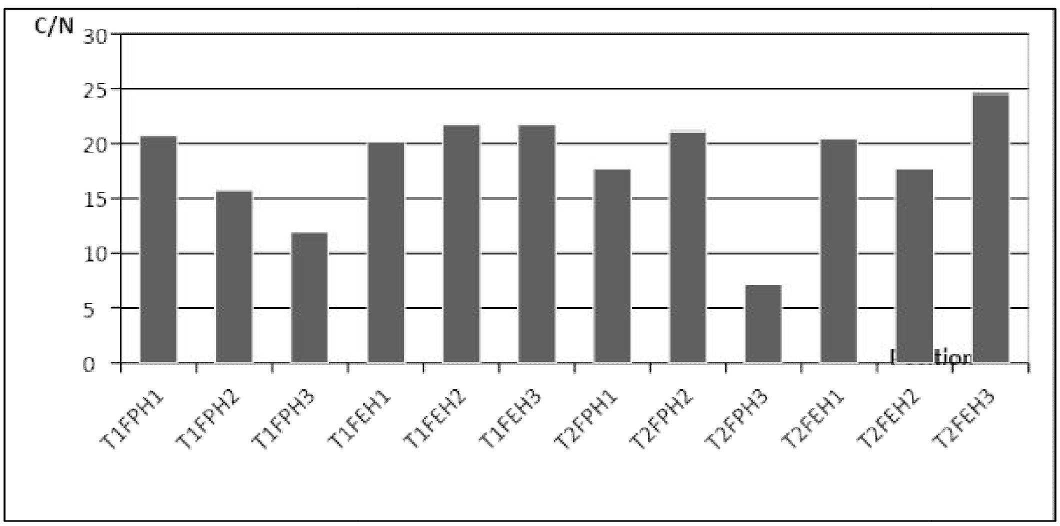

Fig. 10. Change in C/N ratio to stream position

3.3 Statistical Analyzes

3.3.1 Analysis of variance and significance testing

Results show that there is no significant difference between areas far from the stream and areas close to the clay. There is also no significant variation in sand levels in the different layers in the two sectors after ANOVA (Table 2). The results show that there is no significant change in the carbon, nitrogen, organic matter and pH levels in sediment from the 5.p.c. threshold position according to the Fischer test. Whether the pit is distant or near the stream, the levels of chemical elements in the sediment are substantially the same. However, significant variations are recorded by the vertical gradient (Table 3).

3.3.2 Pearson correlation

The Pearson correlation test showed a very good correlation between carbon and organic matter with a correlation coefficient $r = 1$ and a probability $P < 0.0001$. Also, the Pearson correlation test showed good correlations between nitrogen and organic matter with a

Table 2. Comparison of physical soil characteristics between positions and layers

	% clay	% limon	% sand	% physical elements
Position				
F10 (Near)	23,29 a	39,28 a	35,61 a	98,18 a
F40 (far away)	21,08 a	29,27 b	48,38 a	98,73 a
Pr > F	0,8025	0,0180	0,9134	0,8834
Layer				
C1	17,38 b	41.03 a	40.05 a	98.45 a
C2	22,75 a	33,40 a	42.33 a	98.48 a
C3	26.44 a	28,39 a	43.60 a	98.43 a
Pr > F	0,0135	0,1702	0.9972	0.9985
Moyenne	0,22	0,34	0.42	0.98
C.V. (p.c.)	5,80	12,67	12.34	2.73

Nb: Means followed by the same letters in a column are not significantly different from the 5 p.c. threshold

Table 3. Comparison of chemical characteristics between positions and layers

	Carbon (gkg^{-1})	N (gkg^{-1})	C/N	OM (gkg^{-1})	pH
Position					
F10 (Near)	12.19 a	0.65 a	18.60 a	21.01 a	5.72 a
F40 (far away)	10.56 a	0.55 a	18.34 a	18.21 a	5.79 a
Pr > F	0.6724	0.1407	0.1709	0.6697	0.7342
Layer					
C1	19.93 a	1.00 a	19.84 a	34.35 a	5.67 b
C2	9.99 b	0.53 b	19.15 a	17.23 b	5.59 b
C3	4.20 b	0.27 c	16.41 a	7.25 b	6.02 a
Pr > F	0.0119	0.0079	0.6409	0.0119	0.0388
Moyenne	11.38	0.60	18.47	19.61	5.76
C.V. (p.c.)	19.10	14.66	27.83	19.15	2.77

Nb: Means followed by the same letters in a column are not significantly different from the 5 p.c. threshold

	Limon	Sand	Total	Carbon	N	C/N	OM	pH
Clay	-0,491	-0,053	-0,311	-0,897	-0,893	-0,521	-0,897	0,605
	0,323	0,921	0,549	0,015	0,016	0,290	0,015	0,204
limon	1.00000	-0,844	-0,451	0,759	0,816	0,270	0,759	-0,589
		0,035	0,369	0,080	0,048	0,605	0,080	0,219
sand		1.00000	0,728	-0,324	-0,387	-0,011	-0,324	0,305
			0,101	0,530	0,448	0,984	0,530	0,556
total			1.00000	-0,118	-0,084	-0,316	-0,118	0,100
				0,824	0,874	0,542	0,824	0,850
carbon				1.00000	0,989	0,587	1,000	-0,656
					0,000	0,220	< 0,0001	0,157
N					1.00000	0,507	0,989	-0,657
						0,305	0,000	0,156
C/N						1.00000	0,587	-0,649
							0,220	0,163
OM							1.00000	-0,656
								0,157

Fig. 11. Correlation Matrix (Pearson) of sediment characteristics following positions and layers
Values in blue are different from 0 to a level of alpha=0.05 meaning

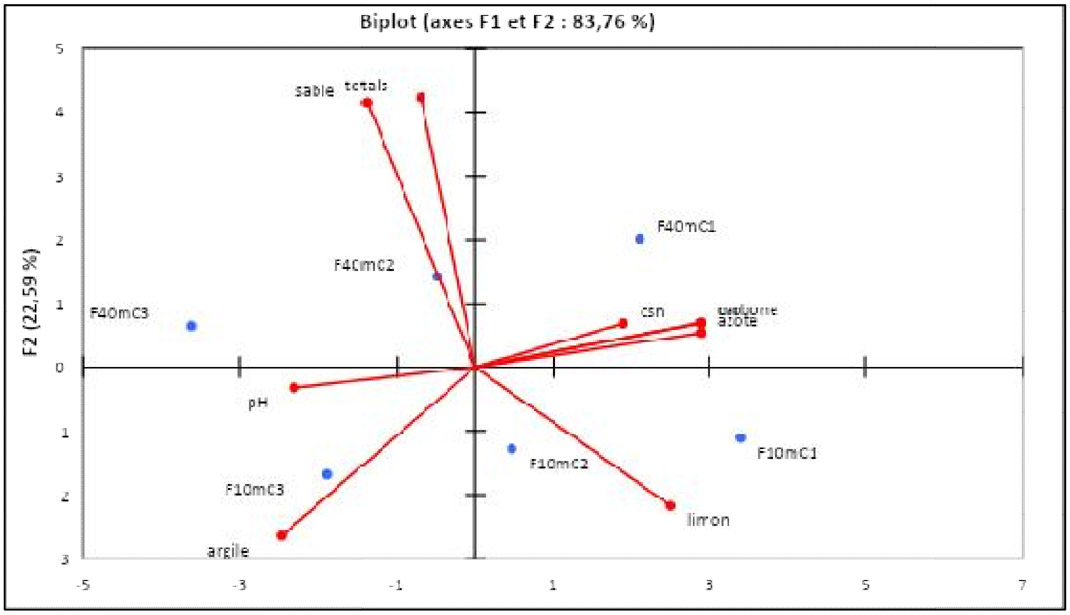

Fig. 12. Primary Component Analysis (PCA) on F1 and F2 axes for physico-chemical characteristics of sediments according to position and layer

correlation coefficient r = 0.989 and a probability P = 0.0001, between carbon and nitrogen with a correlation coefficient r = 0.989 and a probability P = 0.0001. The silt was positively correlated with nitrogen with a correlation coefficient r = 0.816 and a probability P = 0.048. Clay was negatively correlated with carbon (r = -0.897; P = 0.015), nitrogen (r = -0.893; P = 0.016) and organic matter (r = -0.897; P = 0.015). The silt was negatively correlated with sand (r = -0.844; P = 0.035) (Fig. 11).

3.3.3 Principal Component Analysis (PCA)

The CPA showed that 83.76 p.c. information is reported by the F1 and F2 axes. For variables, clay, silt, carbon, nitrogen, organic matter, and pH were well correlated with F1 factor, respectively, with squared cosinus of 0.685, 0.711, 0.944, 0.945, 0.944 and 0.600 and the sand and total of the physical elements that formed the F2 factor respectively with squared cosines of 0.720 and 0.747. For individuals, F10mC1, F10mC3, F40mC1 and F40mC3 constituted the bulk of the information reported by the F1 axis. Finally, the PCA showed a link between silt, carbon, nitrogen, organic matter and F40mC1, F10mC1 individuals; also a link between clay, pH and the individual F10mC3; finally, a link between sand, total physical elements and the F40 mC2 horizon (Fig. 12).

4. DISCUSSION

4.1 Variation in the Physico-chemical Properties of the Sediment by the Horizontal Gradient

Results show relatively low levels of organic matter in the study area. These relatively low levels appear to be characteristic of this medium. They are the response of the disturbances related to successive floods. The accumulation of organic matter is difficult due to the flood and decay phenomena, which is an obstacle to the formation of dense vegetation cover. Successive or periodic river floods are causing changes in riparian ecosystems [27]. These results are identical to the work done by [28], who argue that alluvial soils are also characterized by low concentrations of organic matter in situ due to the absence or near-absence of surface litter. Lower M.O. values have been recorded in sediments away from the stream. These results are inconsistent with those of [29]. These studies show that the highest concentrations of M.O. are found in areas further away from the river (5, 10, 20, 30 m). The results of our investigations could be explained in two non-contradictory ways: first, the high sedimentation rate prevents oxidative degradation of this material at the interface, where degradation processes are generally most active [30]. However, the sedimentary organic matter, partially altered by its river transit, is particularly resistant to bacterial attacks [31]. The organic matter content depends on alluvial sedimentation [32]. The organic matter transported by the river is deposited near the river. This could explain higher levels of organic matter in areas near the stream.

In fact, organic matter deposited in an aquatic environment may have an indigenous origin, and to a more variable degree, an allochthonous origin [33]. A significant fraction of this organic matter is chemically and biologically degraded in the water column. A more or less significant amount (10-60%) occurs at the sediment surface [34] where it will undergo further chemical and biological transformations. A final, most stable fraction will be buried [35]. Numerous studies have shown the different impacts of water front flooding [36,37,38]. Floods and decouples can have beneficial or adverse effects on riparian ecosystems [39,40,41]. The C/N ratio is generally between 10 and 20 or higher. Values between 10 and 20 are typical in the organic matter corresponding to soil plants humified [42]. Values above 18 characterize sediments where terrestrial plant debris has accumulated [43,24]. A low C/N ratio clearly indicates a significant source of organic matter of detritic origin [44].

4.2 Variation in the Physico-chemical Properties of Sediment by Vertical Gradient

At the vertical gradient, our results show that the highest concentrations of MO, CO, and N are mainly in the surface layers. Our results are consistent with those of [26]. There is generally a strong correlation between organic carbon and surface layers. Most of the time the concentration of organic carbon decreases with depth. CO has very low concentrations in depth and its highest concentrations are within the first 20 centimeters of soil [45]. The high rate in this area is due to the biochemical exchanges taking place there, but this may vary depending on the conditions of the environment. The slight increase in C/N in the deep layers reflects faster degradation of nitrogen compounds, which overlaps the results of [36,46,24]. The distribution of organic matter in sediment depends on many and various factors. The content of a sample depends on the inputs themselves, the degree of evolution of the inputs and their dilution by the minerals [28]. In depth, we record the highest pH values. The increase in pH results in the dissolution of organic matter [47]. This may partly explain the low levels of deep organic matter. Nitrogen and organic carbon have a strong similarity in the distribution of levels within pedols. The values of these two variables decrease with depth. This trend towards a decrease in N and C.O. In fact, in the deeper layers, various studies have been carried out [48]. Organic Carbon (CO) and Organic Nitrogen (AO) are reported to have similar behavior in soils, sediments and aquatic environments [12].

4.3 Variation of Organic Matter Content by Particle Size Fractions

Results show that CO is higher in surface areas than in depths containing the highest proportions of clay. The vast majority of authors agree that the levels of clay and C.O. are positively correlated. [49], organic carbon concentration in sediments is related to the abundance of different granu1ometric fractions. There is a significant correlation between organic carbon and particle size distribution. The work of [50,51] indicate that high organic carbon is often associated with a high proportion of clays in sediments. Indeed, the proportion of clay is an important factor in the stabilization of the O.C. in the soil because of the formation of the argilo-humic complex and the physical protection it provides to the O.C. linking to the inside of the aggregates. Furthermore, the stability of aggregates caused by an increase in clay levels would reduce the risk of erosion, which may affect organic carbon reserves [50,51]. There are close relationships between sediment mineralogical composition, including clay fraction and organic matter preservation [52], organic carbon concentration is higher in fine matrix sediments than those with coarse matrix [53,48,32]. However, several studies have shown that there may be significant variability in concentrations in O.C. in the entire profile, in particular for riparian soils [48,45]. This diversity of opinion makes any categorical conclusion difficult.

5. CONCLUSION AND RECOMMANDATION

Results show that sediment from the various study sites has a sando-limonous to limono-clay texture. The observed textural variability in the area is due to the diversity of moveable deposits. This area is characterized by large and extremely rapid sedimentary rearrangements that influence sediment particle size distribution. Organic content of surface sediments on the east bank of the Bandama River in the locality of Sinématiali ranges from 31.98 gkg-1 to 38.98 gkg-1. These relatively average rates would be related to the mineralization of organic matter, which occurs primarily within the first centimeters of the sediment, due to reducing conditions and stream-related inputs. We record a slight decrease in organic matter as we move away from the stream. But these are not significant. However, this indicates that the constant supply of alluvium transported by successive floods and reflecting current hydroclimatic conditions contributes to the organic enrichment of the near stream area. In depth, the rates obtained are very low and range from 6.3 gkg-1 to 8.19 3 gkg-1. These low rates are due to leaching caused by periodic flooding. The MO content is generally higher in sediments of surfaces that contain the lowest proportions of clay. Organic carbon and nitrogen follow almost the same pattern as MO. These results show that successive floods have a direct effect on the dynamics of the physico-chemical properties of the sediments along the shore. An imbalance in organic matter in sediments can have a long-term impact on the vitality of the ecosystem in general.

Based on the results of this study, the authorities should plan shoreline restoration programs to maintain the vitality and diversity of the riparian environment.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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